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FINAL REPORT

SPACELAB USER IMPLEMENTATION ASSESSMENT STUDY

Executive Summary

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Space Division
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FOREWORD

The Spacelab User Implementation Assessment Study was conducted to assess and minimize the capital investment of the National Aeronautics and Space Administration for the integration and checkout of Spacelab payloads such as Langley's Advanced Technology Laboratory. The study was conducted by the Space Division of Rockwell International Corporation under Contract NAS1-12933 for the Langley Research Center. Mr. F. O. Allamby was the technical study manager for the Langley Research Center. In addition, this study received agency-wide guidance and evaluation from the Steering Group for Payloads Operations Concept Studies, directed by Mr. W. O. Armstrong, to maximize the objectivity and applicability of the study data.

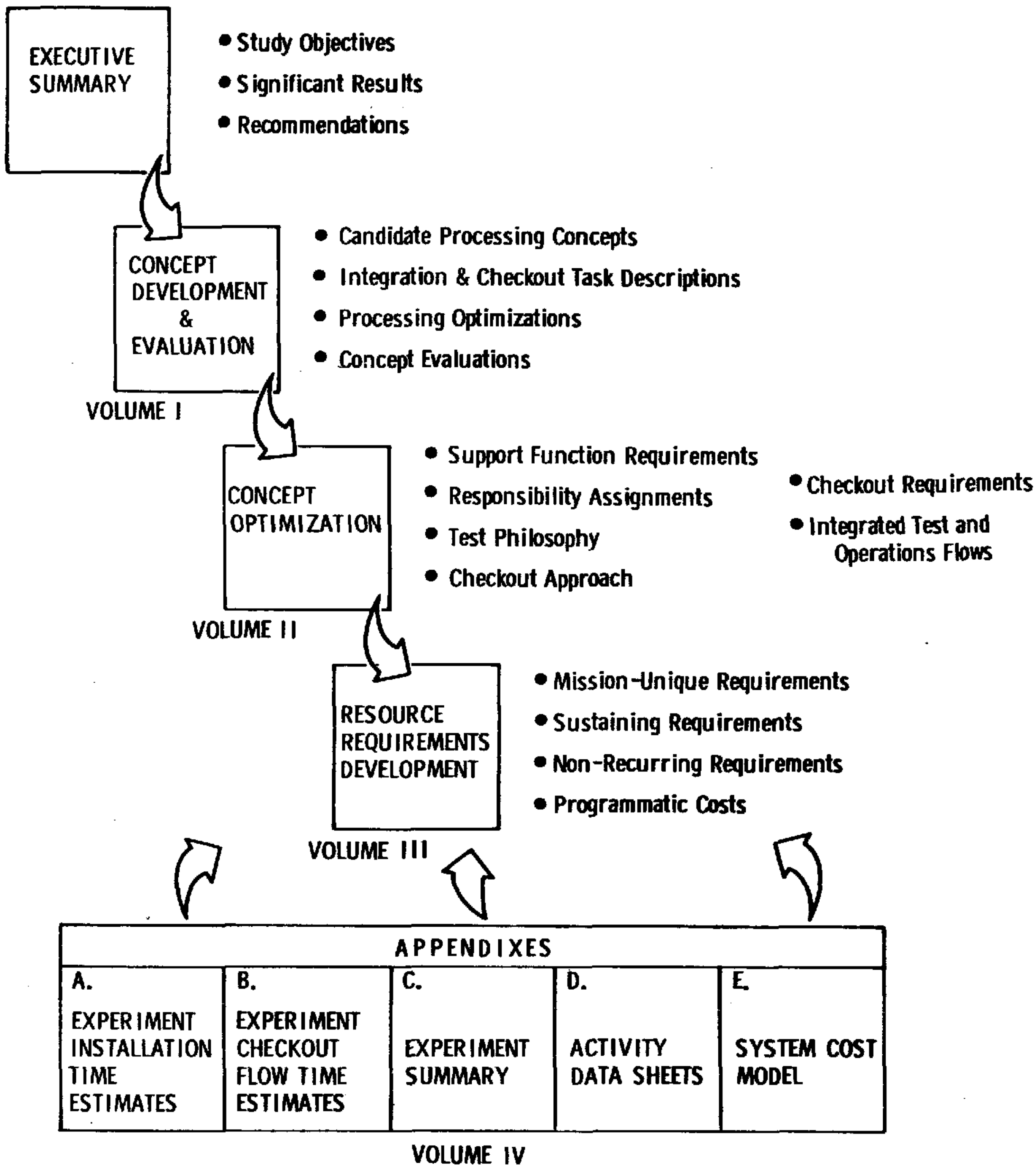
The final report consists of an executive summary and four technical volumes as illustrated in the accompanying figure. A succinct summary of the study is presented in the executive summary. Three of the four technical volumes present the analyses and trades performed during the course of the study. The fourth volume contains five appendixes, which delineate detailed data pertaining to the installation and checkout of Spacelab payloads such as the ATL, and a computer cost model utilized in the compilation of programmatic resource requirements. The contents of the volumes are described below.

EXECUTIVE SUMMARY

- Study overview--objectives, study approach.
- Synopsis of development of candidate processing concepts--complete Spacelab and pallet-only configurations.
- Summary of integration and checkout optimizations--checkout approach, ground operations processing cycle, personnel, ground support equipment and facility requirements.
- Programmatic costing--mission-unique, sustaining, and non-recurring cost estimates for required personnel, material, travel, documentation, ground support equipment, and facilities.
- Concept evaluations--flight-rate sensitivities and concept applicabilities.

VOLUME I. CONCEPT DEVELOPMENT AND EVALUATION

- Complete Spacelab processing concept development.
- Pallet-only processing concept development.



Study Reports

- Results of study optimizations in the areas of checkout requirements, simulator utilization, and configurational changes.
- Flight-rate sensitivities--flight hardware, GSE, facility, and personnel.
- Concept evaluations--integration center/launch site co-location, support module cognizance, WTR implications, general applicability, recommended ATL approach.

VOLUME II. CONCEPT OPTIMIZATIONS

- Supporting functions--development, definitions, and responsibility assignments. Identifies potential software applications.
- Test requirements--checkout approach and requirements, test philosophy, and environmental test requirements.
- Test and operations sequence--development of functional flows, detailed operations, activity data sheets, and integrated flows for both the complete Spacelab and pallet-only processing concepts.

VOLUME III. RESOURCE REQUIREMENTS DEVELOPMENT

- Requirements for mission-unique, sustaining, and non-recurring resources--includes personnel, travel, transportation, material, documentation, GSE, and facilities.
- Programmatic costing--presents cost estimates for all resource requirements.
- Cost-risk analysis--parametric evaluation of deletion of vibra-acoustic, thermal-vacuum and repeat functional tests.

VOLUME IV. APPENDIXES A, B, C, D, AND E

- *Appendix A. Experiment Installation Time Estimates* - Time estimates of the required experiment installation activities including (1) physical installation of experiment hardware in a rack, igloo, or on a pallet; (2) performance of electrical bonding checks; (3) complete mechanical interconnection including fluid and electrical lines; and (4) performance of end-to-end continuity checks between the experiment connector and the interface connector at the experiment module/pallet, support module/experiment module or igloo interfaces.

- *Appendix B. Experiment Checkout Flow Time Estimates* - The general experiment checkout flow plus the time estimates for each individual experiment in the ATL experiment complement. These time estimates detail the time required for:

- Equipment setup and activation, including controls and display equipment.
- Verification of the operation of mechanical devices of both pallet and rack-mounted sensors and auxiliary equipment.
- Verification of data processing/recording equipment and instrumentation concurrent with checkout of the experiments.

• *Appendix C. Experiment Summary* - A summary of the requirements and equipment utilized for each experiment included in the study. The experiments are listed by discipline.

  - Navigation
  - Earth Observations
  - Physics and Chemistry
  - Microbiology
  - Environmental Effects
  - Components and Systems Testing

  The summary for each experiment includes the objectives or purpose, the description of the equipment utilized, the operation of the equipment, and the physical parameters of mass properties and equipment installation location (pallet, rack, igloo).

• *Appendix D. Activity Data Sheets* - Detailed definitions of the test operations associated with each activity defined in the expanded functional blocks (detailed functional flows). The activity data sheets describe the operations involved and the resources utilized to accomplish the processing cycle. They cover the entire cycle from initial experiment installation through the various integration levels (Experiment, III; Spacelab, II; Orbiter Cargo, I), and the refurbishment of the pallets, racks and/or igloos, following the completion of the mission.

• *Appendix E. System Cost Model* - Description of computer cost model utilized in the study to compile the derived resource requirements into mission-unique, sustaining, and non-recurring cost categories.

Within each volume, the term "concept" is used repeatedly and data are presented with respect to Concepts I through VIII. The concepts referred to pertain to alternate integration and checkout approaches for both the complete Spacelab (support module, experiment module, and pallet) and the pallet-only Spacelab configuration. The following two tables define, in general terms, each of the eight processing concepts that were definitized in this study.

Complete Spacelab Processing Concepts

CONCEPT	OWNER			INTEGRATION SITE	
	SM/EM SHELL*	RACKS & RACK SETS	PALLET	EXPERIMENT EQUIPMENT	SPACELAB
I	IC	IC	IC	IC	IC
II	LS	IC	IC	IC	LS
III	LS	IC	IC	USER	LS
IV	LS	USER	USER	USER	LS
V	USER	USER	USER	USER	USER

*SUPPORT MODULE, SUPPORT SYSTEMS, & EXPERIMENT MODULE STRUCTURE

Pallet-Only Processing Concepts

CONCEPT	OWNER		INTEGRATION SITE	
	PALLET	IGLOO*	EXPERIMENT EQUIPMENT	SPACELAB
VI	IC	LS	USER	LS
VII	IC	LS	IC	LS
VIII	USER	LS	USER	LS

*SUPPORT SYSTEMS IGLOO AND EQUIPMENT

ABBREVIATIONS AND ACRONYM LIST

AAFE	Advanced Application Flight Experiments
ADDAS	Automated Digital Data Acquisition System
AEDC	Atomic Energy Development Center
AIM	Apogee Insertion Motor
AM	Airlock Module (Skylab)
ARINC	Aeronautical Radio, Inc.
ARS	Atmospheric Revitalization System
ASO	Airborne Science Office
ATCS	Active Thermal Control Subsystem
ATL	Advanced Technology Laboratory
ATM	Apollo Telescope Mount (Skylab)
CCTV	Closed Circuit Television
CDMS	Command and Data Management System
CER	Cost Estimating Relationship
C.G.	Center of Gravity
CKTS	Circuits
CM	Command Module (Apollo)
CPSE	Common Payload Support Equipment
CRT	Cathode Ray Tube
CSM	Command and Service Module (Apollo)
CV-990	Convair airplane used as test bed in airborne research by NASA-Ames Research Laboratory
DOMSAT	Domestic Satellite (commercial geosynch communications relay)
DPC	Data Processing Center
DWGS	Drawings
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
EDS	Experiment Discipline Specialist
EGSE	Electronic Ground Support Equipment
E/I	End Item (hardware)
EM	Experiment Module
EMC	Electromagnetic Compatibility
EMI/RFI	Electromagnetic Interference/Radio Frequency Interference
EPDS	Electrical Power and Distribution System
ERNO	European consortium developing Spacelab
ESRO	European Space Research Organization

FMEA	Failure Mode Effects Analysis
FO	Flight Operations
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
IC	Integration Center (sometimes inferred to be MSFC)
ICD	Interface Control Drawing
I/F	Interface
IMS	Information Management System
INSP	Inspection
IPS	Instrument Pointing System
IU	Instrument Unit (Saturn V Program)
JCL	Job Control Language
JSC	Lyndon B. Johnson Space Center
KSC	John F. Kennedy Space Center
LL	Lower Limit
LS	Launch Site
MCC	Mission Control Center (at JSC)
MCP	Monitor and Control Panel
MDA	Multiple Docking Adapter (Skylab)
MGT	Management
MIL-SPEC	Military Standard Specification
MSFC	Marshall Space Flight Center
MSOB (O&C)	Manned Spacecraft Operations Bldg (now Operations & Checkout)
MSS	Modular Space Station
MP	Mission Planning
NASCOM	NASA Communications Network
NCR	Non-Conformance Report
OBCO	On-Board Checkout
OCC	Operations Control Center (at Spacelab user's site)
O&C	Operations & Checkout Building (formerly MSOB)
OCP	Operational Checkout Procedure
OIT	Orbiter Integrated Test
OMS	Orbital Maneuvering System (Shuttle)
OWS	Orbital Workshop (converted S-IVB structure--Skylab)
OPF	Orbiter Processing Facility
P	Pallet or Pallet Section
PI	Principal Investigator
PS	Payload Shroud (Skylab)
PSS	Payload Specialist Station
QC	Quality Control
R	Rack or Rack Sets
RAU	Remote Acquisition Unit
R/I	Receiving/Inspection
R&QA	Reliability and Quality Assurance

SC 105	Spacecraft 105 (Apollo)
SCM	System Cost Model
SE	Systems Engineering
SIM	Scientific Instrument Model
SL	Spacelab
SM	Support Module
SPECS	Specifications
SSP	Space Shuttle Program
STDN	Space Tracking and Data Network
STS	Space Transportation System
SUIAS	Spacelab User Implementation Assessment Study
TCR	Test and Checkout Requirements
TDRS	Tracking and Data Relay Satellite
T&O	Test and Operations
U	User (inferred to be Langley)
UL	Upper Limit
WBS	Work Breakdown Structure
WTR	Western Test Range

CONTENTS

ILLUSTRATIONS

TABLE

1.0 INTRODUCTION

One of the primary uses of the Space Shuttle will be to conduct sortie missions with the Spacelab. The combination of the Shuttle and the Spacelab will place the advantages of economical space operations within the reach of many investigators who would otherwise never be able to participate. Major efforts are being expended by the NASA to define and develop the flight hardware and operational procedures for the Space Shuttle. Similar efforts are being expended by the NASA in conjunction with the ESRO activities to develop a Spacelab that is compatible with the Space Shuttle and will accommodate multiple users in conducting economical space operations. This study, the "Spacelab User Implementation Assessment Study," was conducted to definitize one aspect of the user-Space Shuttle-Spacelab interrelationship, integration and checkout activities.

Langley Research Center is conducting studies of a sortie mission-compatible Advanced Technology Laboratory (ATL) that is particularly suited to Langley's technical expertise and research endeavors. A Langley in-house study (TM X-2813) not only defined three representative ATL Spacelab payloads, but also identified a baseline concept of experiment ownership and processing that would provide an opportunity to develop low-cost approaches to the integration and checkout activities that combine significant cost savings and reduced cycle time between experiment concept and data return from space.

Figure 1.1-1 summarizes the three baseline ATL Spacelab payloads. The two primary characteristics of the ATL payloads that make them ideally suited as the model for the study are: (1) multiple/diverse technological disciplines, and (2) multiple Spacelab configurations. The broad range of experiment hardware and processing requirements associated with the various disciplines and the complete Spacelab and pallet-only Spacelab configurations will facilitate the assessment and application of the study results by other Shuttle-Spacelab users.

Utilizing the baseline ATL experiments as the Spacelab payload models and the generalized processing concept defined in TM X-2813, which emphasized the retention of ownership-cognizance-responsibility of experiment hardware by the principal investigators, this study was conducted to definitize alternate processing concepts. The scope of the activities defined in this study included mission operations analysis and requirements definition, interface hardware design and fabrication, and both preflight and postflight tests and operations. Mission-unique, sustaining, and non-recurring resource requirements were derived for each of the alternate processing concepts. The potential applicability of each of the concepts to the general Spacelab user community, as well as the preferred ATL approach, was also developed.

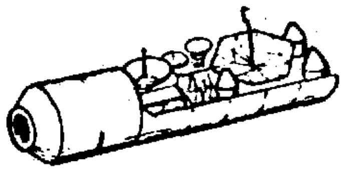
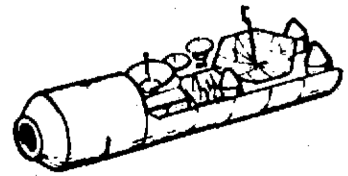
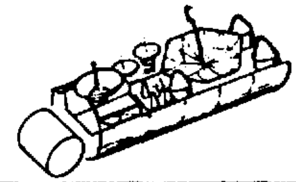
	PAYLOAD NO. 1	PAYLOAD NO. 2	PAYLOAD NO. 3
			
MISSION UNIQUE	NV-3 MULTIPATH MEASUREMENTS EO-2 TUNABLE LASERS EO-5 LASER RANGING EO-9 RF NOISE PH-5 RADIATION ENVIRONMENT MB-3 BIO CELL ELEC FIELD OPACITY	EO-3 MULTISPECTRAL SCANNER EO-6 MICROWAVE ALTIMETRY PH-1 WAKE DYNAMICS MB-2 MICROORGANISM TRANSFER MB-4 BIO CELL ELECTRICAL CHAR MB-5 BIO CELL GENERAL PROPERTIES EN-2 MATERIAL FATIGUE CS-2 ZERO-G STEAM GENERATOR	NV-1 MICROWAVE INTERFEROMETER NV-2 AUTONOMOUS NAVIGATION EO-1 LIDAR MEASUREMENTS EO-4 RADIOMETER EO-7 SEARCH AND RESCUE AIDS EO-8 IMAGING RADAR
MULTIPLE MISSION	PH-2 BARIUM CLOUD RELEASE PH-3 AEROSOL PROPERTIES PH-4 NEUTRAL GAS PARAMETERS MB-1 COLONY GROWTH EN-1 MICROORGANISM SAMPLING XST- CONTAMINATION MONITOR	PH-3 AEROSOL PROPERTIES PH-6 METEOR SPECTROSCOPY MB-1 COLONY GROWTH EN-1 MICROORGANISM SAMPLING EN-3 NON-METALLIC MATERIALS XST- CONTAMINATION MONITOR	PH-2 BARIUM CLOUD RELEASE PH-4 NEUTRAL GAS PARAMETERS PH-6 METEOR SPECTROSCOPY EN-1 MICROORGANISM SAMPLING EN-3 NON-METALLIC MATERIALS XST- CONTAMINATION MONITOR

Figure 1.1-1. Baseline ATL Payloads

2.0 STUDY OBJECTIVES

The overall objective of the Spacelab User Implementation Assessment Study was to develop alternate integration and checkout concepts for Spacelab payloads in sufficient detail, and supported by sound ground rules, guidelines, facts, and analyses, to assist the NASA in its definition of and planning for Phases C and D of Spacelab operations. The overriding criteria in the development of the concepts were to minimize both the initial and recurring costs to the NASA for ground support equipment, facilities, and personnel.

The four primary objectives that were established to achieve the overall study objectives were: (1) synthesis of candidate processing concepts, (2) derivation of integration and checkout requirements and optimization of each of the processing concepts, (3) programmatic costing, and (4) evaluation of each concept to establish its potential applicability. The key factors and considerations associated with each primary objective are delineated below.

SELECTION OF CANDIDATE CONCEPTS

Concept Drivers. Ownership/cognizance of flight hardware, and site of integration activities were determined to be the two major factors in defining alternate concepts.

Processing Options. Maintaining cognizance of the experiment hardware by the user, and the Space Shuttle by the launch site, and always performing Shuttle/Cargo integration (Level I) at the launch site still results in 243 processing options of a complete Spacelab configuration.

Candidate Concept Selection. Eight concept rejection rationale were formulated based upon unacceptable combinations of ownership and integration sequences. These rationale reduced the options to nine viable concepts. The data that would be generated in the definitization of some of the viable concepts would be similar and, thus, a further reduction to five prime candidates for processing of a complete Spacelab configuration was accomplished. Three comparable pallet-only configuration processing concepts were also defined.

REQUIREMENTS AND OPTIMIZATIONS

Tests and Operations. A checkout approach was formulated that reflected a progressive buildup of assembly levels and minimized retest. Only functional tests comparable to flight activities (set up, calibrate, and operate) and interface verification tests were included. Use of on-board equipment capabilities was adopted if reduction in ground support equipment requirements resulted. A technique for simultaneous software and hardware integration was defined. Hardware processing flows were developed that minimized the involvement times of Spacelab modules.

Supporting Functions. Identification and definition of the analysis, mission planning, design, fabrication, and test procedure/report activities were developed. Primary and secondary responsibilities and manpower estimates to accomplish each activity were derived. Use of computer-aided analyses and design was emphasized.

Resource Requirements. Mission-unique, sustaining and non-recurring resource requirements were derived. A personnel staffing approach was developed. Administrative organizations were synthesized. Travel, material, transportation, documentation, shipping, and maintenance requirements were established. GSE and facility requirements were also defined.

PROGRAMMATIC COSTING

Mission-Unique. Cost estimates for personnel, materials, travel, computer time, etc., that could be directly attributed to a specific flight, were developed.

Sustaining. Cost estimates for personnel, maintenance, and institutional base support were developed.

Non-Recurring. Cost estimates for personnel to adapt an operational Spacelab to the unique requirements of a user and the capital investments for GSE and facilities were developed.

CONCEPT EVALUATIONS

Flight-Rate Sensitivities. A parametric evaluation of the impact of flight rates on Spacelab modules, GSE, facilities, and personnel/staffing requirements was conducted.

Concept Applicability. Adoption of each processing concept by potential Spacelab users was evaluated. Co-location of the integration center and the launch site was considered. Implications of Western Test Range operations were examined. Spacelab support module ownership/cognizance alternatives were also evaluated.

3.0 SIGNIFICANT STUDY RESULTS

This section presents a summary of the more significant results of the analyses of the study. The subdivisions in this section correspond to the four primary objectives of the study described in the previous section.

3.1 SELECTION OF CANDIDATE CONCEPTS

In the development of ground processing alternatives, numerous factors must be considered, but the two primary drivers are (1) the ownership of the flight hardware and (2) the integration site. Ownership implies cognizance, configuration management, maintenance, and primary responsibility for the hardware. Performance of Level I (Orbiter/cargo), Level II (Spacelab), and Level III (experiment) integration at separate geographical locations will directly influence the number and characteristics of the processing options.

Figure 3.1-1 illustrates the two key drivers and the variables associated with each driver. The three options considered for each variable were (1) a user center (U), (2) integration center (IC), and (3) launch site (LS). In order to facilitate the development of data pertaining to personnel travel, shipping, and logistics the three centers were assumed to be geographically separated.

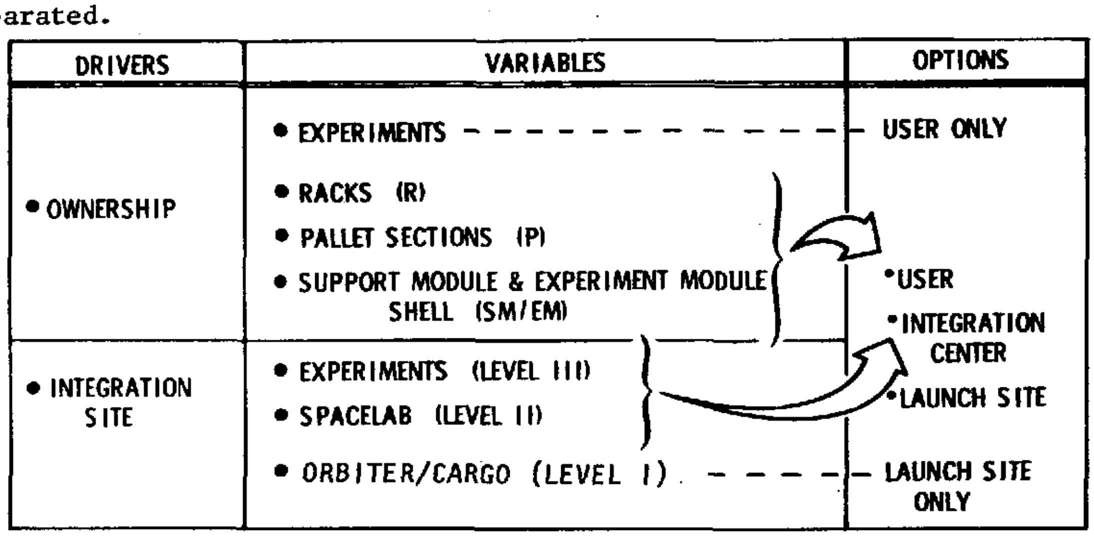


Figure 3.1-1. Key Processing Alternative Considerations

Two of the variables, experiment ownership and Shuttle integration site were established as user and launch site, respectively. Langley's in-house study (TM X-2813) established the desirability of the Spacelab user retaining ownership of experiment hardware. Physical constraints dictate that Shuttle integration occur at the launch site. The remaining five variables coupled with the three options result in a 3^5 matrix of possible processing alternatives as depicted in Figure 3.1-2.

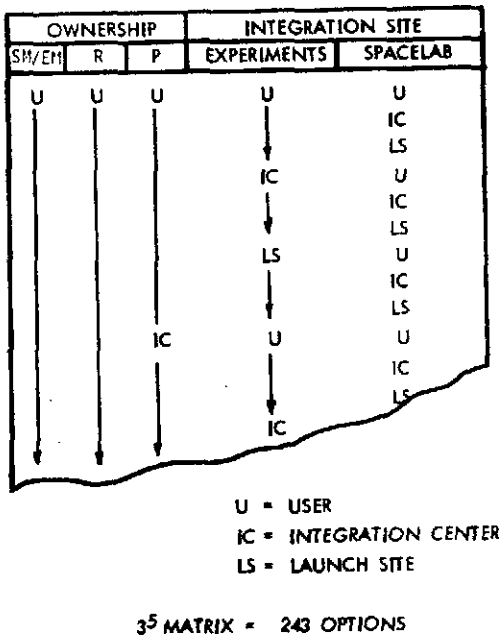


Figure 3.1-2. Matrix of Processing Alternatives

The matrix of processing alternatives was reduced to nine by application of the rejection rational of Table 3.1-1. The rationale is based primarily upon a logical progression of assembly of and configuration control of the flight system. For example, if the user owns the SM/EM, it would be illogical for either the IC or LS to own the racks and pallets because the SM/EM is required at a higher order of assembly. It would be unreasonable for the user to be responsible for a hardware item/integration level at an assembly level that is greater than that of either the IC or LS. A similar relationship exists between the IC and LS: ownership or integration by the LS at any assembly level precludes ownership or integration by the IC at a higher assembly level.

Table 3.1-1. Processing Alternative Rejection Rationale

	FOR CONCEPTS WHERE ...	REJECT COMBINATIONS CALLING FOR ...
OWNERSHIP	———	SPLIT-OWNERSHIP OF R/P
	USER IS SM/EM OWNER	OTHER R/P OWNERS
	IC IS SM/EM OWNER	LS AS R/P OWNER
INTEGRATION SITE	LS IS R/P OWNER	EXPMT INTEGRATION AT IC
	IC IS R/P OWNER	EXPMT INTEGRATION AT LS
	LS IS SM/EM OWNER	SPACELAB INTEGRATION OTHER THAN AT LS
	ALL SPACELAB HARDWARE (SM/EM, R/P IS OWNED BY ONE CENTER)	SPACELAB INTEGRATION OTHER THAN AT OWNER'S SITE
	EXPERIMENT INTEGRATION IS AT LS	SPACELAB INTEGRATION OTHER THAN AT LS

The nine remaining viable processing options were further reduced to five (Figure 3.1-3) based upon the similarity of the data that would be generated and to achieve a broad spectrum of candidate concepts (Figure 3.1-4).

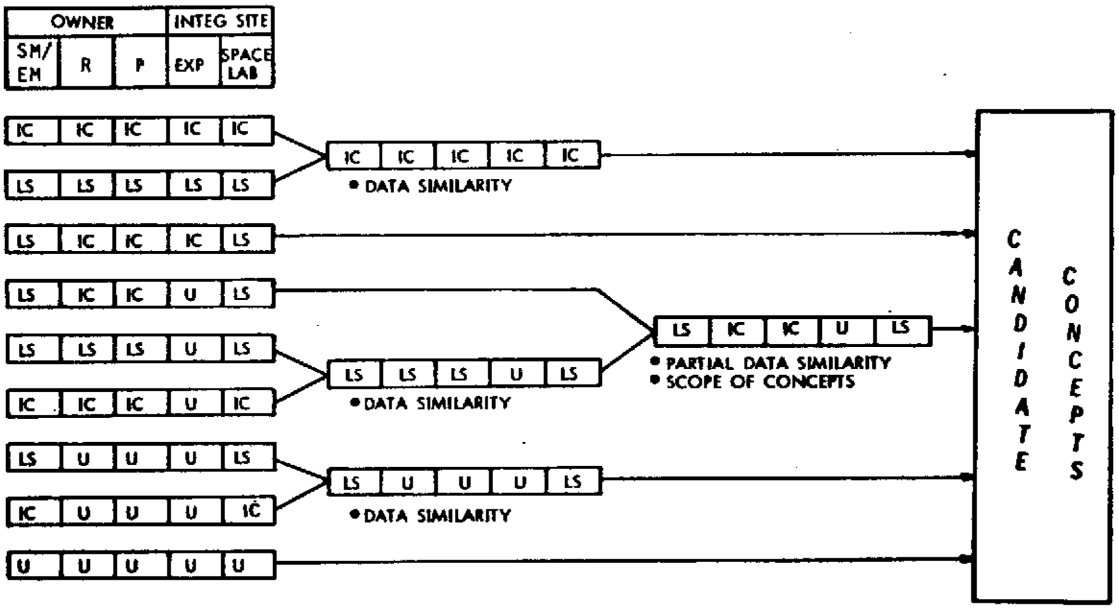


Figure 3.1-3. Viable Complete Spacelab Processing Concepts

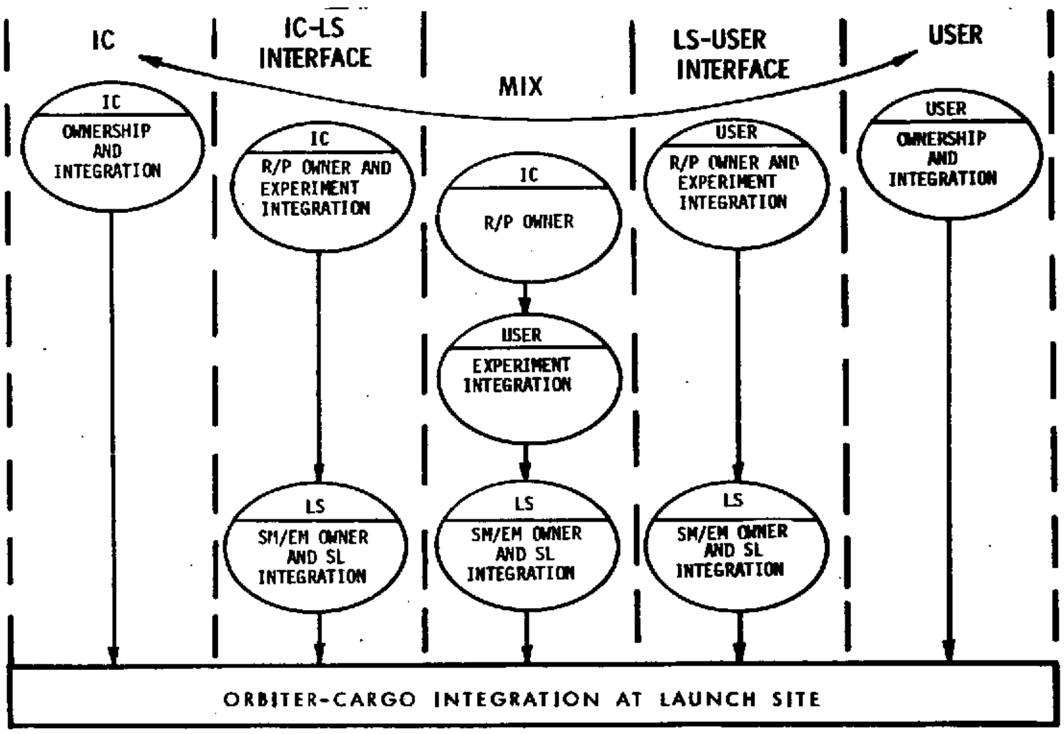


Figure 3.1-4. Spectrum of Concepts

Table 3.1-2 summarizes the five complete Spacelab processing concepts that were definitized in this study. Three pallet-only Spacelab processing options were also developed in the study and are summarized in Table 3.1-3. As the study progressed, it became apparent that the three pallet-only concepts were comparable to three of the complete Spacelab concepts. That is, similarities exist between Concepts III and VI, II and VII, and IV and VIII.

Table 3.1-2. Complete Spacelab Processing Concepts

CONCEPT	OWNER			INTEGRATION SITE	
	SM & EM SHELL	RACKS	PALLET	EXPERIMENT EQUIPMENT	SPACELAB
I	IC	IC	IC	IC	IC
II	LS	IC	IC	IC	LS
III	LS	IC	IC	USER	LS
IV	LS	USER	USER	USER	LS
V	USER	USER	USER	USER	USER

Table 3.1-3. Pallet-Only Processing Concepts

CONCEPT	OWNER		INTEGRATION SITE	
	PALLET	IGLOO*	EXPMT EQUIP	SPACELAB
VI	IC	LS	USER	LS
VII	IC	LS	IC	LS
VIII	USER	LS	USER	LS

*SUPPORT SYSTEM IGLOO & EQUIPMENT

3.2 REQUIREMENTS AND OPTIMIZATIONS

The integration and checkout of Spacelab payloads was subdivided into two major sets of activities: (1) test and operations, and (2) support functions. The test and operations activities, which pertain solely to the processing of the hardware through preflight and postflight operations, were optimized to minimize involvement times of Spacelab modules. The supporting functions, which include operations analysis, mission planning, integration and checkout requirements definition, and design and fabrication of interface hardware were optimized to achieve a manageable steady-state personnel staff and minimize responsibility transfer between centers. Resource requirements for both major activities were derived and include personnel as well as support service requirements.

TEST AND OPERATIONS

The basic guidelines used in the synthesis of the test and operations sequences for all candidate processing concepts are summarized in Figure 3.2-1.

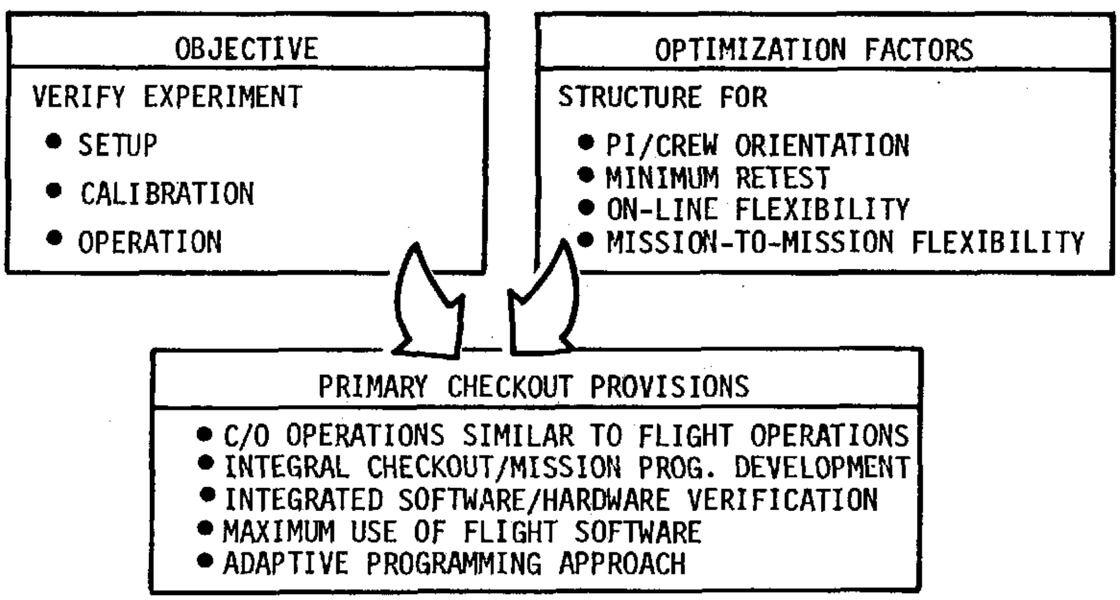


Figure 3.2-1. Checkout Guidelines

It was assumed that the performance capability of the experiments was verified prior to receipt of the experiment hardware at the Level III integration site. Thus, the objective during Level III integration was to verify that experiments could be set up, calibrated, and operated both individually and in planned combinations after installation of equipment in racks and/or on pallet sections.

Optimization factors in the development of the test and operations sequences included the direct participation of the PI/payload specialist crew members. This approach would provide the payload specialists with the opportunity to become more intimately familiar with the flight hardware as well as enhance checkout operations by having the personnel most knowledgeable about the experiments actively participating in the checkout.

One of the primary contributors to the duration of checkout activities of aerospace hardware is repeat testing. Previous manned space programs exhibited two characteristics that warranted the repetitive testing: (1) in general, these previous programs were developmental in nature; and (2) the majority of the spacecraft equipment was crew safety-related. During the Shuttle era, both the Space Shuttle and the Spacelab will be operational carriers that provide standardized and repeatable support to payloads. Crew safety provisions will have been verified and only functional checkout will be required. Although crew safety is a prime criterion in design of payloads, the payloads themselves are not crew safety equipment. Thus, repeat testing of payload equipment and interfaces between payloads and the Spacelab and/or the Shuttle was not included in the checkout sequences developed in this study. The capability of payload recovery and reflight also permits a relaxation in payload testing requirements in the Shuttle-Spacelab era.

Flexibility of checkout operations is also required. If resolution of discrepancies or incorporation of revisions cannot be accommodated on-line, then a duplication of effort and additional processing time would result. The corrective action/modification would first be verified off-line, then implemented and verified on-line. This situation is particularly applicable to software. By using adaptive programming and real-time editing, both on-line and mission-to-mission flexibility can be achieved.

If the primary checkout provisions of Figure 3.2-1 are included, the objective and optimization factors can be realized. The adopted checkout approach should essentially duplicate planned flight operations. That is, the checkout activities should reflect the planned flight activities. This approach is applicable to both software and hardware verification. As the checkout approach simulates flight, integrated/simultaneous software-hardware verification is achieved. Also, software unique to checkout activities should be minimal; the actual flight software should be adequate for most checkout activities and maximum use of it should be made. The desired flexibility in accommodating changes in the manual operations of equipment can be accomplished by procedural changes. An adaptive programming approach is required to achieve the same flexibility with software.

Figure 3.2-2 illustrates the checkout alternatives. Neither manual nor automatic operations of the on-board systems are practical. Manned operations would be too time-consuming. Total automation would result in excessive hardware and software costs and all but preclude flexible operations. Also, the manual and automatic approaches are not representative of the anticipated flight operations. A mixture of manual and automated operations (computer-aided) will be the nominal approach for flight operations.

The primary factor in implementing a computer-aided approach is the capability of the Spacelab on-board data management system. Evaluation of the currently defined data management capability of the Spacelab indicates that one computer is dedicated to support system operations; a second computer is allocated solely for payload operations; a third computer is available in a standby/backup mode for either of the dedicated computers. The computers are in the support module in the complete Spacelab configuration, and in the systems igloo in the pallet-only configuration. The capacity of these computers to handle their assigned operations is more than adequate. Even with an allowance for unique checkout requirements over and above the "set up, calibrate, operate" functions of flight, there is still significant design margin in the computers for growth of requirements.

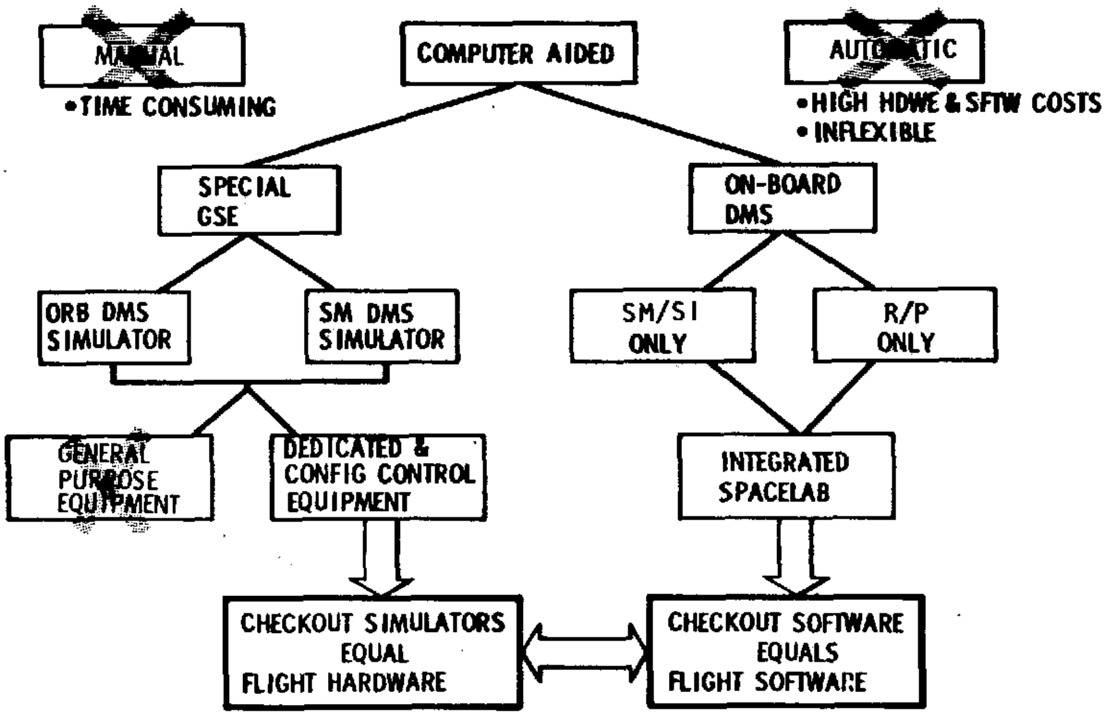


Figure 3.2-2. Alternate Checkout Implications

Use of the on-board data management system during integrated Spacelab operations is feasible and practical. However, use of the flight hardware during Level III integration will appreciably increase the involvement time of Spacelab modules and thus the required complement of modules to support the Spacelab traffic model. A similar Shuttle problem will exist if compatibility between the Spacelab and the Shuttle were postponed until actual mating/assembly of the Shuttle/Spacelab. Therefore, the use of simulators was evaluated.

Although general-purpose equipment (computers) could and should be used for the development of the checkout/flight software, verification and integration of the software and hardware should be conducted on dedicated, configuration-controlled equipment. Regardless of the location of the simulators, the configuration control should be maintained by the "owner" of the flight hardware being simulated. In this manner, the checkout simulators will remain the equivalent of the flight hardware; both the user of the simulator and the owner of the flight hardware being simulated will be confident that upon assembly of the flight hardware, compatibility will exist and only interface verification is required. This approach will preclude the requirements for development of unique software for checkout utilizing general-purpose equipment; the checkout software will actually be the flight software.

The development and verification of the checkout/flight software for Level III integration activities is illustrated in Figure 3.2-3. In those cases where software is desirable, the principal investigator can develop a requirements package and convert this package to a modular software package in an off-line computer. The necessary services from the support systems can be integrated with the experiments requirements in the same manner. The baseline checkout/flight tapes for each experiment are incorporated into the Spacelab data management simulator for Level III integration activities. A real-time editor capability is also recommended to provide the desired in-line flexibility.

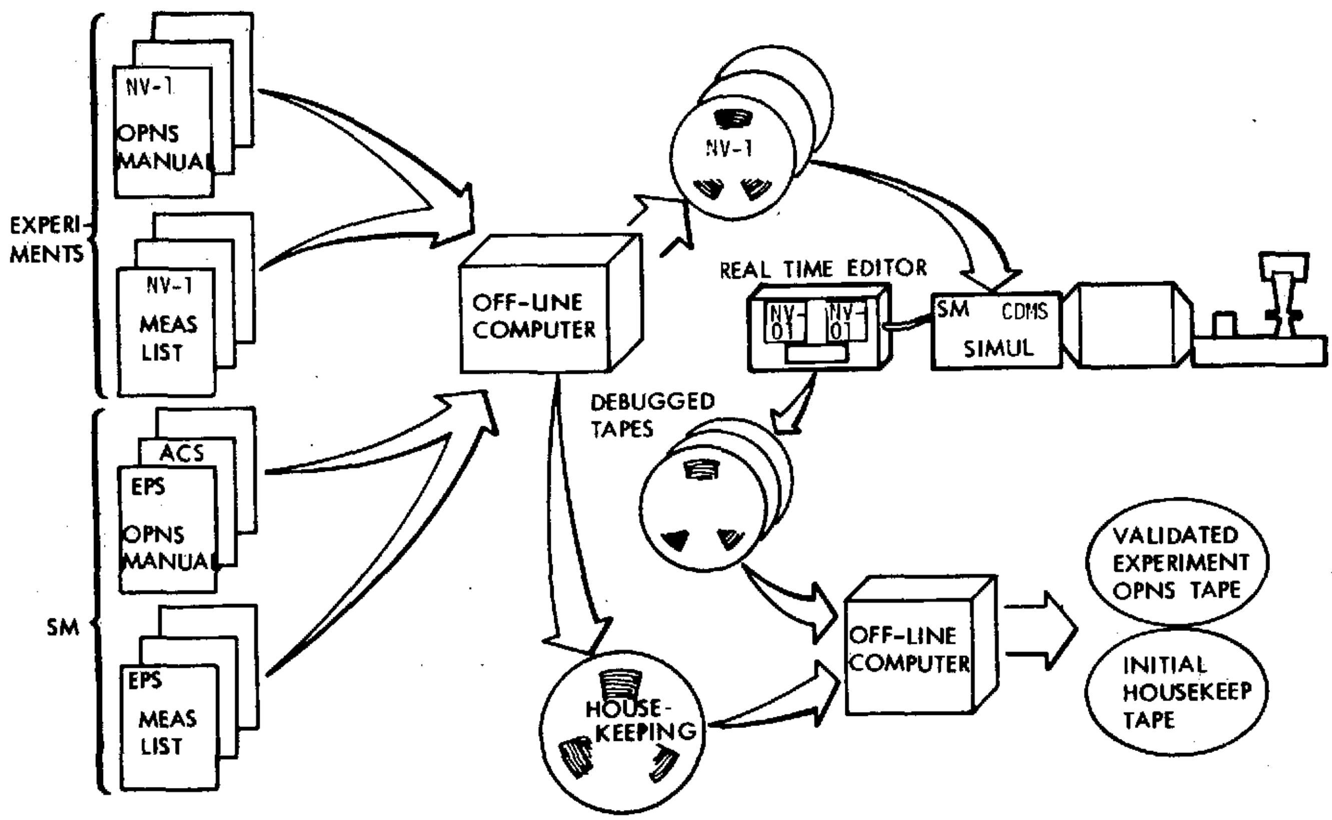


Figure 3.2-3. Level III Integration Modular Software Development

The checkout approach selected in this study utilizes the PI/payload specialists during the tests and operations; these personnel actually conduct the tests. Their expertise is utilized and, at the same time, flight operations training and familiarization can be accomplished. With this approach, a mission or training simulator is not recommended.

Based upon the checkout approach delineated above, a detailed sequence of test and operations was developed. Figure 3.2-4 depicts the methodology used. Functional block diagrams were prepared for each of the processing concepts.

Each block was expanded at least two additional levels of detail. Activity data sheets were prepared for each expanded block, that definitize each step in the processing of the hardware, and include time estimates for each activity. These time estimates were summarized into an integrated flow plan recognizing practical overlap and parallel activities.

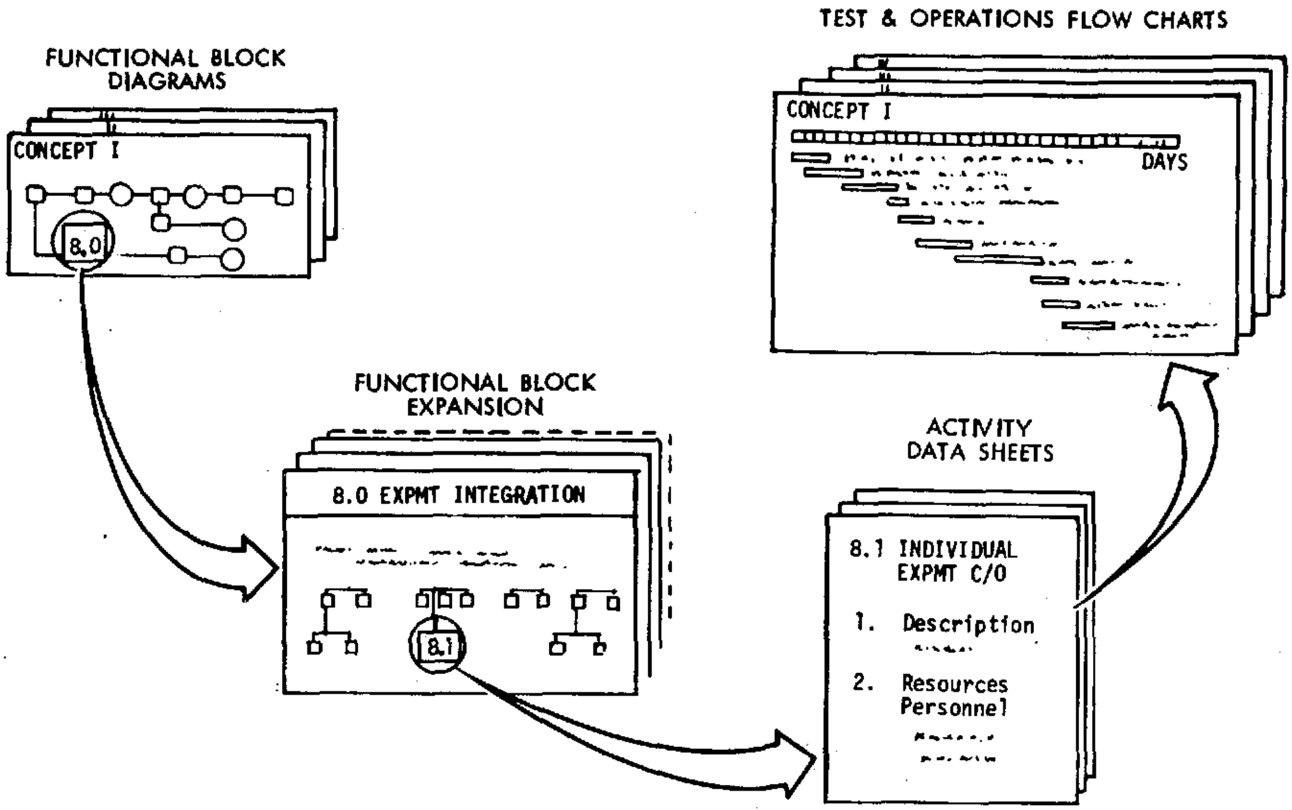


Figure 3.2-4. Development of Test and Operations Time Sequences

Table 3.2-1 summarizes the serial processing time from initiation of Level III integration through postflight refurbishment for the complete Spacelab configuration. Table 3.2-2 presents comparable data for the pallet-only configuration. All time estimates are based upon a single eight-hour shift/five-day work week. The nominal processing time for the concepts is about six calendar months. Concepts III and VI required the longest period for processing their respective configurations because of the second post-flight shipment after refurbishment of the Spacelab modules ($\approx$ 6 days).

Table 3.2-1. Summary of T&O Times for the Complete Spacelab Processing Concepts

BLOCK	MAJOR FUNCTIONAL ACTIVITY	BLOCK TIME (DAYS)	OVERLAP TIME	PARALLEL TIMES	SERIAL PROCESSING TIMES I	II	III	IV	V
1.0	EXPERIMENT SHIPMENT	6.0		X					
2.0	EXPERIMENT INSTALLATION	22.0			22.0	22.0	22.0	22.0	22.0
3.0	CONNECT SM INTERFACE SIMULATOR	5.7	2.5		3.2	3.2	3.2	3.2	3.2
4.0	EXPERIMENT INTEGRATION	36.0			36.0	36.0	36.0	36.0	36.0
5.0	GSE DISCONNECT	0.9		X					
6.0	RACKS/PALLET SHIPMENT	6.7				6.7	6.7	6.7	
7.0	MATE RACKS/PALLET - EM/SM SHELLS	3.0			3.0	3.0	3.0	3.0	3.0
8.0	SPACELAB INTEGRATION	10.4			10.4	10.4	10.4	10.4	10.4
9.0	SPACELAB SHIPMENT TO LAUNCH SITE	3.6			3.6				3.6
10.0	SPACELAB OFFLOAD	2.7			2.7				2.7
11.0	ORBITER CARGO INTEGRATION	4.7	0.2*		4.5	4.7	4.7	4.7	4.5
12.0	LAUNCH OPERATIONS	4.2			4.2	4.2	4.2	4.2	4.2
13.0	MISSION OPERATIONS (REF)	5.0			5.0	5.0	5.0	5.0	5.0
14.0	POSTFLIGHT OPERATIONS	1.9			1.9	1.9	1.9	1.9	1.9
15.0	SPACELAB MOVE TO MSOB	2.6				2.6	2.6	2.6	
16.0	SPACELAB SHIPMENT FROM LAUNCH SITE	5.4			5.4				5.4
17.0	DEMATE EM/SM SHELLS	1.2			1.2	1.2	1.2	1.2	1.2
18.0	RACKS/PALLET SHIPMENT	6.7				6.7	6.7	6.7	
19.0	REFURBISH RACKS/PALLET	8.2			8.2	8.2	8.2	8.2	8.2
20.0	EXPERIMENT SHIPMENT	5.5		X					
21.0	REFURBISH SUPPORT SYS & EM/SM SHELLS	8.2	8.2	X					
22.0	POST-REFURBISH RACKS/PALLET SHIPMENT	6.5					6.5		
		TOTAL (WORKING DAYS)			111.3	115.8	122.3	115.8	111.3

*CONCEPTS I AND V ONLY

Table 3.2-2. Summary of T&O Times for Pallet-Only Processing Concepts

BLOCK	MAJOR FUNCTIONAL ACTIVITY	BLOCK TIME (DAYS)	OVERLAP TIMES	PARALLEL TIME	SERIAL PROCESSING TIME CONCEPT VI	VII	VIII
1.0	EXPERIMENT SHIPMENT	7.0/1.0		X			
2.0	EXPMT INSTALL. (PALLET/IGLOO)	21.0			21.0	21.0	21.0
3.0	CONNECT & C/O IGL/ORBITER SIM SET	5.7	3.7		2.0	2.0	2.0
4.0	EXPERIMENT C/O & INTEGRATION	36.0			36.0	36.0	36.0
5.0	GSE DISCONNECT	2.5		X			
6.0	PALLET/IGLOO SHIPMENT	3.5			3.5	3.5	3.5
7.0	P/IGL & PSS EQUIP ARRIVAL & R/I	2.4			2.4	2.4	2.4
8.0	MATE PALLET & IGLOO (SUPPORT SYST)	2.7			2.7	2.7	2.7
9.0	SPACELAB INTEGRATION	10.2			10.2	10.2	10.2
10.0	ORBITER CARGO INTEGRATION	4.2			4.2	4.2	4.2
11.0	LAUNCH OPERATIONS	4.2			4.2	4.2	4.2
12.0	MISSION OPERATIONS (REF)	5.0			5.0	5.0	5.0
13.0	POSTFLIGHT OPERATIONS	1.9			1.9	1.9	1.9
14.0	REFURBISH SUPPORT SYSTEMS IGLOO	7.5		X			
15.0	PALLET/IGLOO SHIPMENT	5.0			5.0	5.0	5.0
16.0	REMOVE EXPMTS/EQUIP FROM P/IGLOO	5.0			5.0	5.0	5.0
17.0	EXPERIMENT SHIPMENT	2.5		X			
18.0	REFURB/RECONFIG PALLET & IGLOOS	3.0			3.0	3.0	3.0
19.0	POST-REFURB P/IGLOO SHIPMENT	5.6			5.6		
		TOTALS			111.7	106.1	106.1

SUPPORTING FUNCTIONS

In order to establish and define the required mission-unique support functions, a detailed task-oriented, work breakdown structure (WBS) was constructed. Figure 3.2-5 presents the composite WBS for the integration and checkout of a Spacelab payload. The primary mission-unique support functions are summarized in the *Mission Analysis and Planning*, *Mission Operations*, and *System Engineering* blocks. Each subdivision of these blocks was further expanded to at least one lower level of detail. Except for the -*50 Test and Operations* entry, all tasks associated with the *Experiment Integration & Checkout*, *Spacelab Integration*, and *Orbiter Cargo Integration* blocks were also considered to be mission-unique supporting functions. Mission-unique support services such as personnel travel, shipping, computer run time, acquisition of interface hardware materials, and publication costs are grouped under the heading of *Program Operations Support*. Support associated with the administering of the program (sustaining effort) is grouped under the *Program Management* heading. In order to complete the WBS, the *Ground Support Equipment* and *Facilities* headings, which pertain primarily to non-recurring capital investments, were also included.

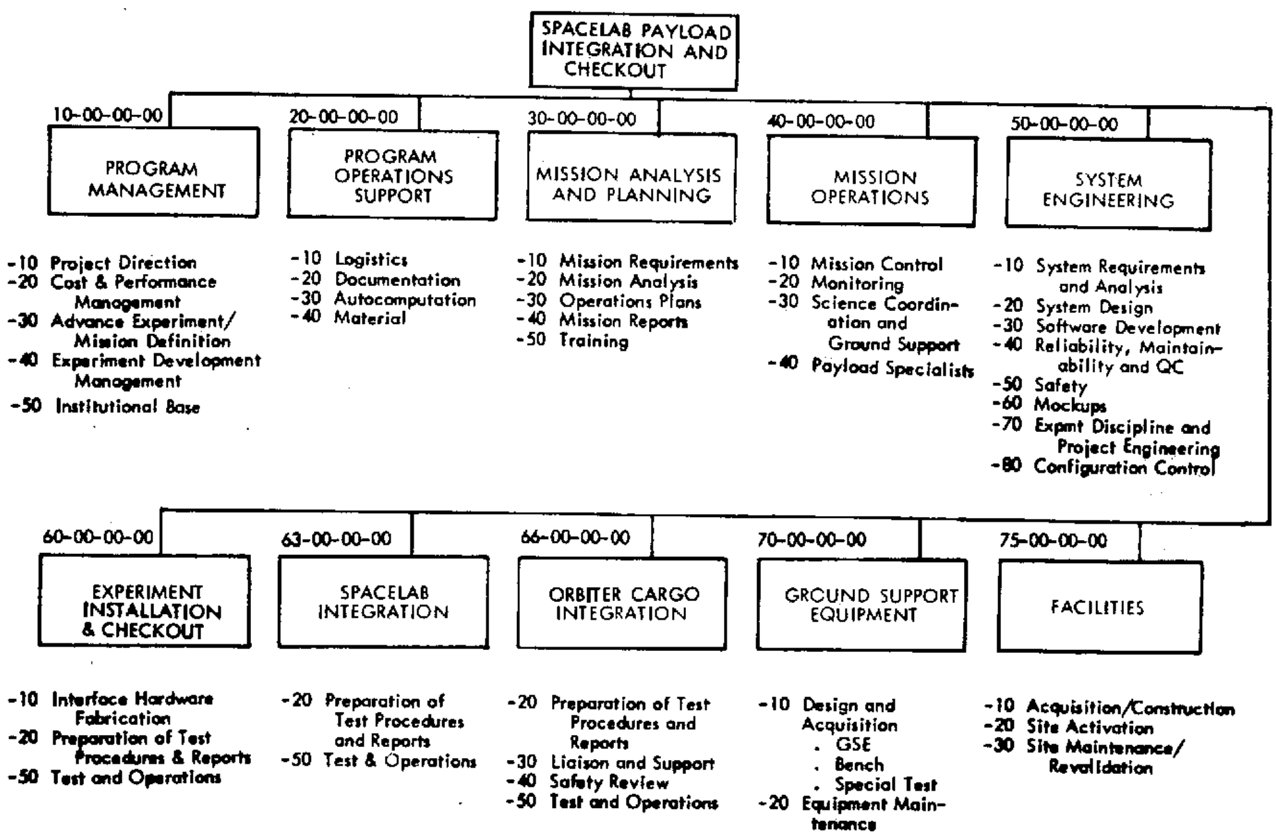


Figure 3.2-5. Integration and Checkout WBS

Each identified task of the mission-unique support functions was evaluated to determine the required effort and the interrelationship of the tasks. A ground rule in the estimation of the manpower required to perform a task was that the basic effort was the same regardless of the center performing the task. Thus, the variation in effort between processing concepts for a given task was dependent solely upon the number of centers involved and the resultant coordination, review, and approval required.

In order to establish primary, secondary, and/or supporting efforts for each task, responsibility assignment criteria were developed. These criteria are summarized in Figure 3.2-6. The two main themes of the criteria are (1) maintenance of owner cognizance and responsibility, and (2) configuration control. As pointed out in the development of the checkout approach, the PI/payload specialist actively participates in the test and operations. These personnel maintain cognizance and responsibility for their experiments and experiment hardware throughout the processing cycle. This same ownership-cognizance-responsibility relationship is applicable to all other items of flight hardware.

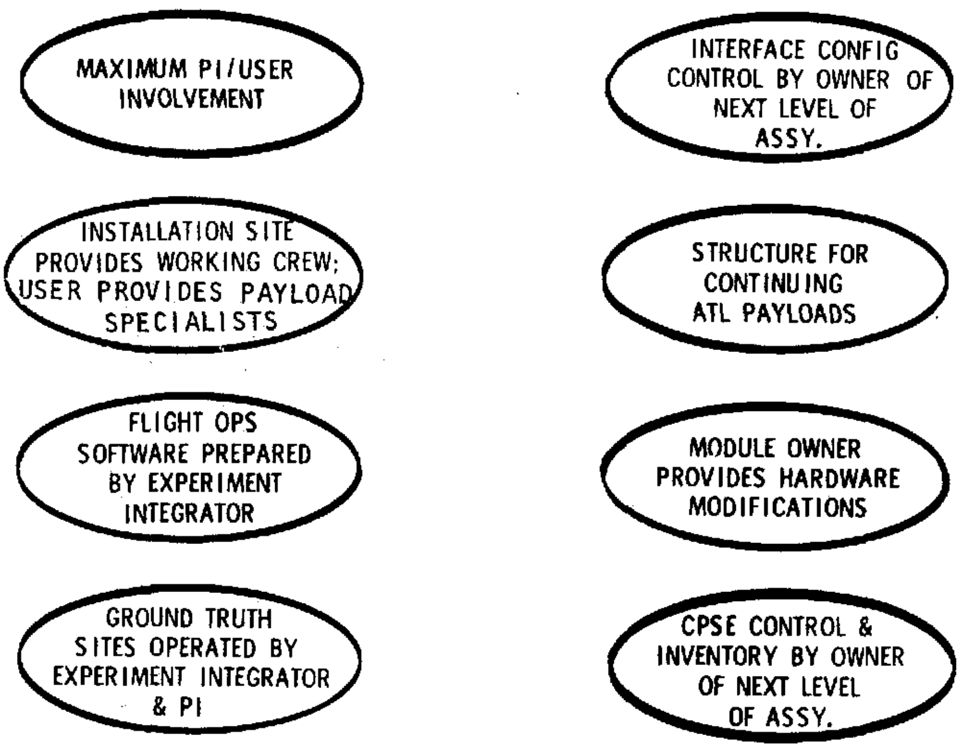


Figure 3.2-6. Responsibility Assignment Criteria

Configuration control is considered to be equally important in achieving maximum efficiency of operations in continuing programs such as the ATL, Spacelab, and Space Shuttle. The center responsible for the higher order of assembly must exercise configuration control on all interfaces with lower order assemblies because only this center has the perspective and visibility to ascertain the effects of interface variances on subsequent flight hardware. Also, as the assembly level increases, the schedule criticality increases. The center responsible for the assembly of flight hardware or software elements must be confident that compatible interfaces will exist. It is believed that this confidence can be achieved by the proposed configuration control technique.

One exception to the continuity of involvement is the use of technicians. Because of the inevitable differences in some of the ground support equipment, procedures, facilities, and organized labor agreements it is recommended that only local technician help be planned.

A compliation of the required man-months of effort to perform the mission-unique tasks associated with one flight is presented in Table 3.2-3. Because of the interrelationship between hardware processing activities and the test procedures and reports preparation, both supporting function and test and operations efforts are included in the "Experiment Installation and Checkout," "Spacelab Integration," and "Cargo Integration" headings.

Table 3.2-3. Mission-Unique Manpower Estimates - Per Mission (Man-Months)

WBS TASK / CONCEPT	I			II & VII			III & VI			IV & VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
MISSION ANALYSIS	25	46	7	25	44	10	62	--	10	62	10	63	7
MISSION OPERATIONS	53	38	2	53	32	9	83	--	9	83	9	87	2
SYSTEMS ENGINEERING	61	176	21	61	162	44	173	52	44	209	44	223	21
EXPERIMENT INSTALL. & C/O	6	126	--	6	141	3	74	65	3	144	3	134	--
SPACELAB INTEGRATION	--	34	8	--	6	29	7	--	29	6	29	36	8
CARGO INTEGRATION	1	8	15	1	8	16	8	--	16	8	16	8	17
GSE	--	4		--	4	--	4	--		4		4	
TOTALS	146	432	53	146	397	111	411	117	111	516	111	555	55
		631			654			639		627		610	

Only very minor differences in required manpower effort were identified to integrate and check out the two Spacelab configurations (complete Spacelab and pallet-only). Therefore, the estimates for comparable processing concepts for the two configurations were defined as being the same.

The variation in requirements between concepts reflects the number of centers involved, which would be expected. However, the difference between concepts is not significant. Although the differences are a consideration in concept selection, they are not a discriminator.

In order to develop the personnel staffing requirements, the mission-unique tasks were assembled in a logic flow diagram as illustrated in Figure 3.2-7. Evaluation of the task flow diagram indicated that there were three major phases to the integration and checkout cycle: analysis, design and fabrication of interface hardware, and test and operations. If only a single payload were considered, personnel staffing could be intentionally sized to minimize the total integration and checkout duration. This approach would result in approximately nine months for the analysis and design/fabrication tasks and a nominal six-month duration for the test and operations tasks. Further decreases in the tests and operations tasks are not practical; only so many personnel can work on a given set of hardware at any one time.

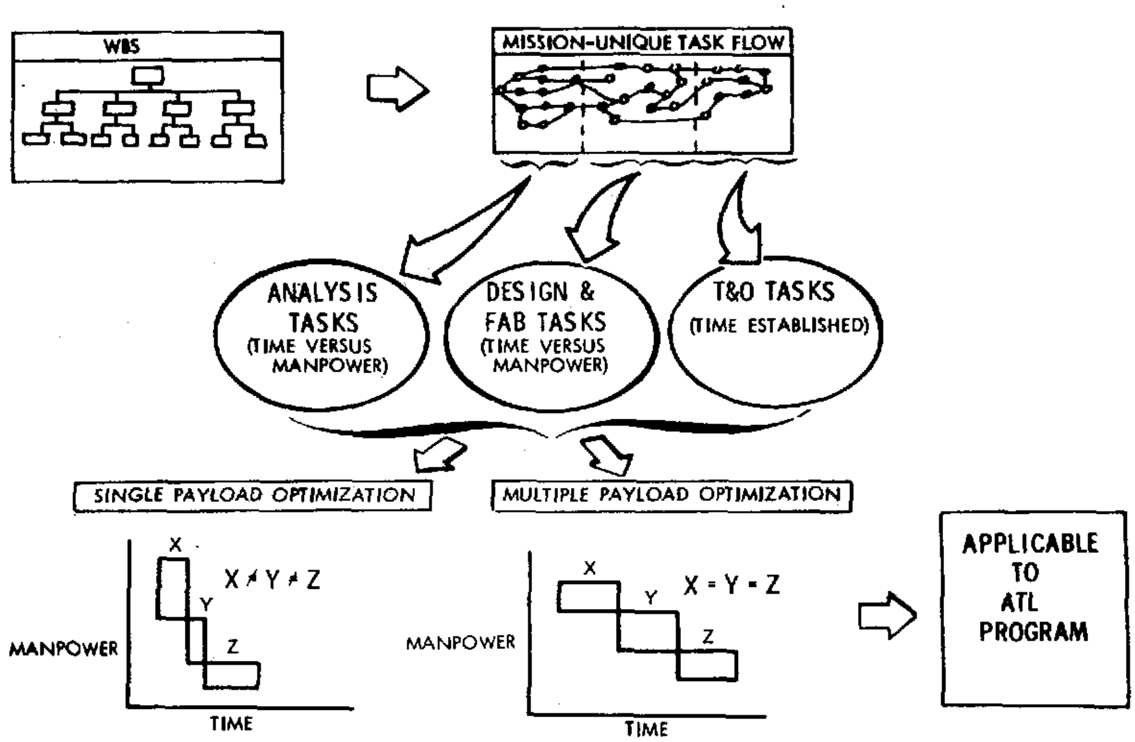


Figure 3.2-7. Manpower Utilization Approach

In a continuing program such as the ATL, the shortest ground operations duration is not necessarily the most efficient approach. Maximum utilization of the assigned staff is the most cost-effective approach. Trade studies indicated that if the analysis tasks and the design/fabrication tasks were intentionally scheduled to equal the six-month duration of the tests and operations tasks, and the staffing were sized to reflect this scheduling, then an optimized use of personnel could be achieved. This optimization was based upon skill codes (operations analyst, systems engineer, designer, programmer, etc.), not just man-levels.

Figure 3.2-8 illustrates the preferred personnel staffing approach for a program that has a flight rate of two per year. Each phase of the integration and checkout cycle is scheduled for six months. One flight will occur every six months. By cycling the personnel associated with each phase to a subsequent mission, gainful utilization of manpower can be realized. In any six-month period, all three phases are accomplished but each phase pertains to a different flight. The work accomplished in any calendar year is equivalent to the processing effort required for two payloads. But actually, four payloads are involved; three are in process at any given time, and the total cycle time for any one payload is 18 months.

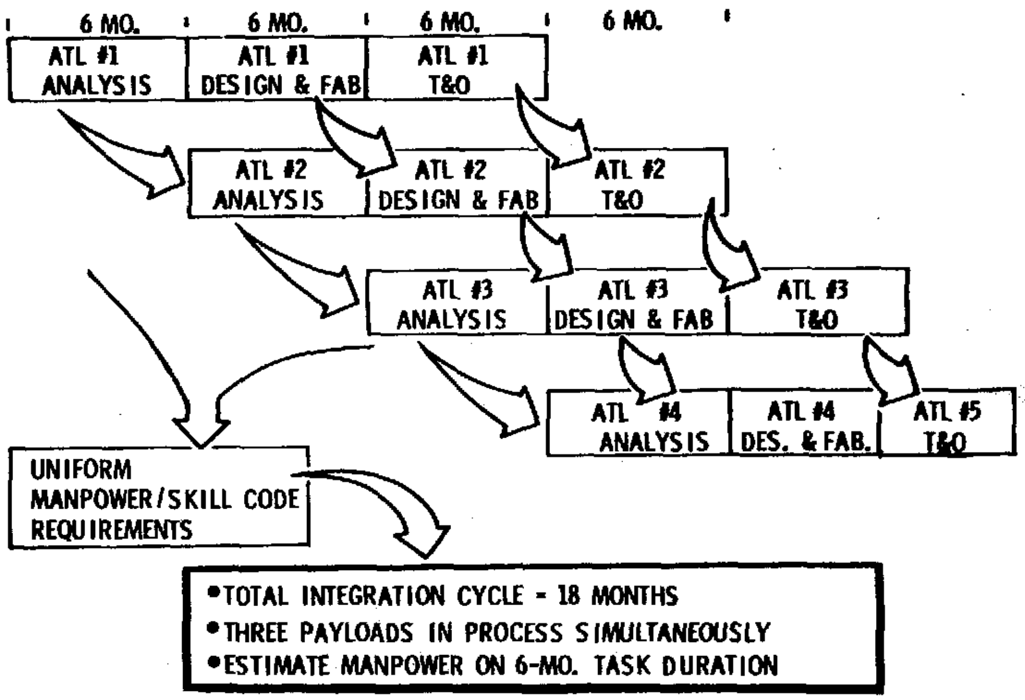


Figure 3.2-8. Optimized Use of Manpower

RESOURCE REQUIREMENTS

Staffing requirements for mission-unique and sustaining functions, manpower requirements for non-recurring activities, and ground support equipment and facility requirements are delineated below.

Personnel

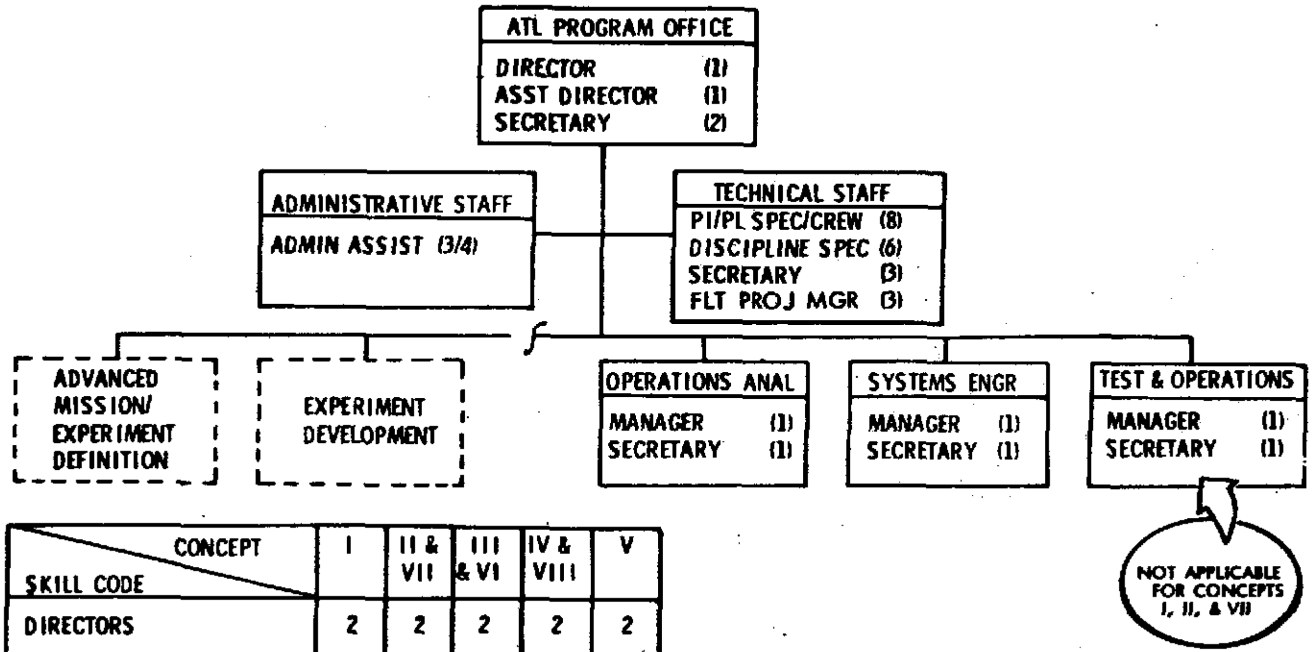
Based upon the optimized approach for the use of personnel, described previously, the resultant man-level requirements for the performance of all the mission-unique tasks are presented in Table 3.2-4. In some cases it was not practical to utilize all of the personnel of a particular skill code on a full-time basis for only two flights per year. User part-time help could consist of the designers, programmers, and test personnel associated with the development of the experiment hardware. In fact, this use of hardware development personnel will expedite the integration and checkout tasks because of their expertise with the experiment hardware and software. Part-time personnel listed for the integration center and launch site could be shared with other Spacelab users. This sharing of personnel is also advantageous because it fosters cross-correlation of procedures, assembly and checkout techniques, and problem solutions between Spacelab users.

Table 3.2-4. Mission-Unique Personnel Requirements (Two Flights Per Year)

SKILL CODE / CONCEPT	I			II & VII			III & VI			IV & VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
OPERATIONS ANAL.	8	9	1	8	9	2	15	0	2	15	2	15	1
SYSTEMS ENGINEER	9	18	3	10	15	6	22	3	6	23	6	26	3
DESIGNER	5	(6) 11	(2) 0	5	(6) 10	(2) 1	(4) 8	(6) 6	(2) 1	(12) 12	(2) 1	(12) 13	(2) 0
PROGRAMMER	(2) 0	(3) 3	(1) 0	(2) 0	(3) 3	(1) 0	(3) 3	0	(1) 0	(3) 3	(1) 0	(3) 3	(1) 0
CODER	0	1	0	0	1	0	1	0	0	1	0	1	0
TEST ENGINEER	(2) 0	9	(3) 0	(2) 0	8	(3) 1	9	(3) 0	(3) 1	9	(3) 1	10	(3) 0
TEST TECHNICIAN	0	(5) 9	(8) 0	0	(5) 8	(11) 0	(12) 0	(6) 0	(11) 0	(5) 8	(11) 0	(5) 9	(8) 0
MECHANIC	0	(3) 3	0	0	(3) 3	0	1	(6) 1	0	(6) 2	0	(6) 2	0
TOTALS	(4) 22	(17) 63	(14) 4	(4) 23	(17) 57	(17) 10	(19) 59	(21) 10	(17) 10	(26) 73	(17) 10	(26) 79	(14) 4
		(35) 89			(38) 90			(57) 79		(43) 83		(40) 83	

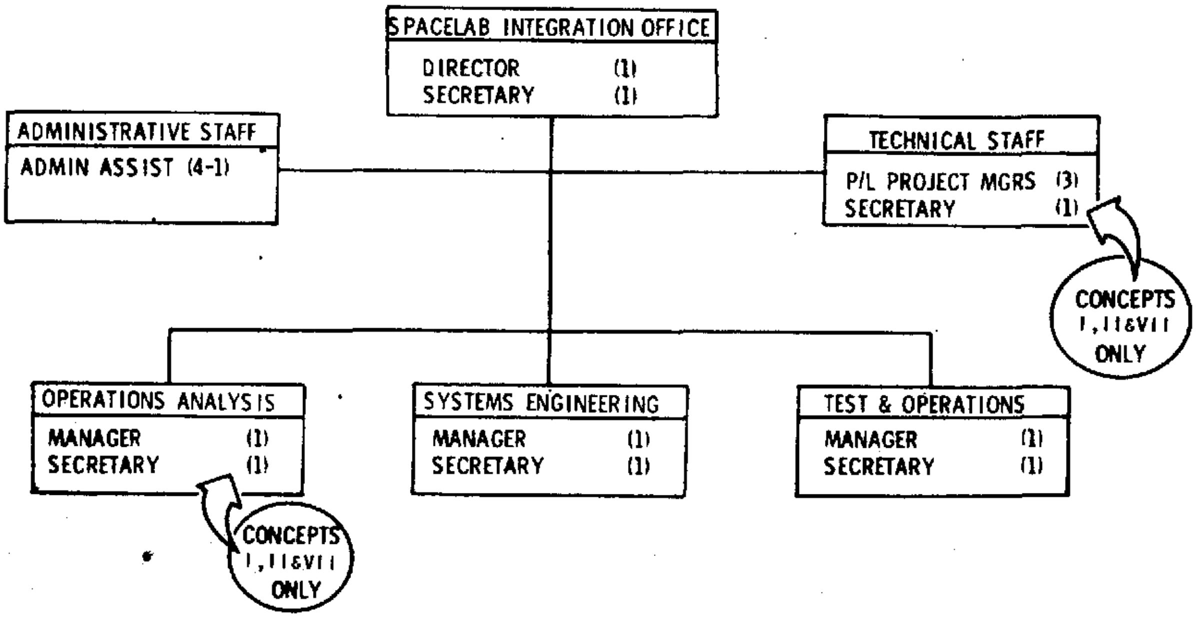
LEGEND:
(XX) PART TIME
XX FULL TIME

Sustaining manpower requirements were developed by synthesizing organizations for the various centers. Figures 3.2-9, 3.2-10 and 3.2-11 present an organizational structure for each of the involved centers. As the tasks vary at the centers for the various concepts, the appropriate variations with concept are identified on the figures.



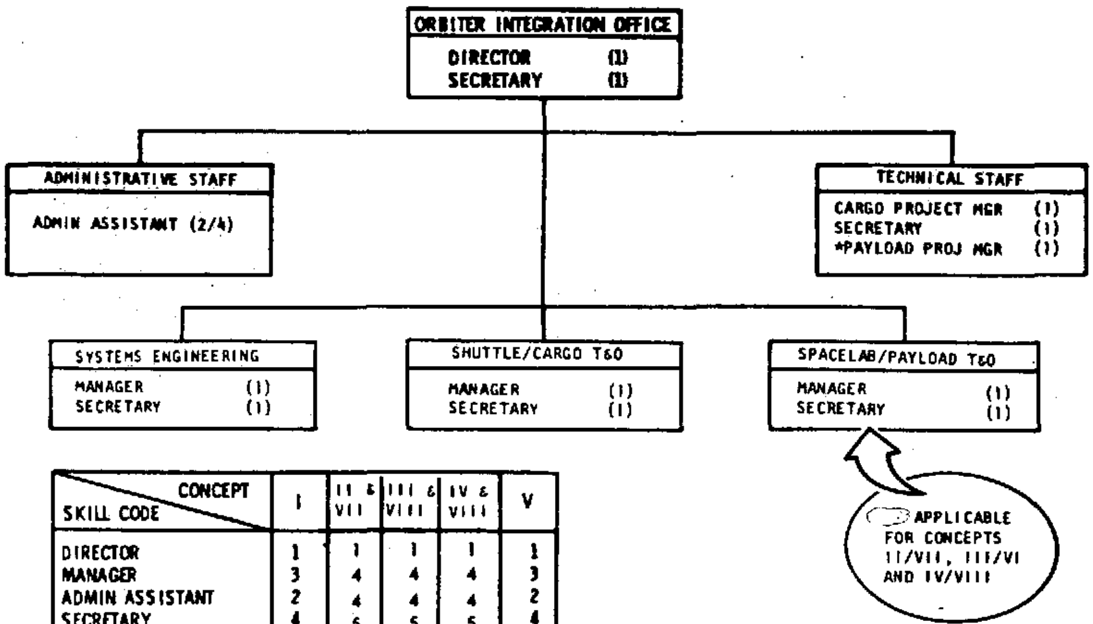
SKILL CODE \ CONCEPT	I	II & VII	III & VI	IV & VIII	V
DIRECTORS	2	2	2	2	2
MANAGERS	5	5	6	6	6
SENIOR TECH SPECIALISTS	14	14	14	14	14
ADMIN ASSISTANTS	3	3	4	4	4
SECRETARIES	7	7	8	8	8
	31	31	34	34	34

Figure 3.2-9. User Center Sustaining Organization



SKILL CODE \ CONCEPT	I	II & VII	III & VI
DIRECTOR	1	1	1
MANAGER	6	6	2
ADMIN ASSISTANT	4	4	1
SECRETARY	5	5	3
	16	16	7

Figure 3.2-10. Integration Center Sustaining Organization



SKILL CODE \ CONCEPT	I	II & VII	III & VIII	IV & VIII	V
DIRECTOR	1	1	1	1	1
MANAGER	3	4	4	4	3
ADMIN ASSISTANT	2	4	4	4	2
SECRETARY	4	5	5	5	4
	10	14	14	14	10

*REPLACES CARGO PROJECT MANAGER IN CONCEPTS II/VII, III/VI AND IV/VIII

Figure 3.2-11. Launch Site Sustaining Organization

Attributing the entire sustaining organizations to the integration and checkout activities associated with two flights per year is unrealistic. Therefore, a pro-ration of the sustaining organization was applied. Table 3.2-5 summarizes the pro-rations.

Table 3.2-5. Selective Proportion of Supporting Personnel Costs

	APPLICABLE CHARGES (%)	RATIONALE
USER CENTER		
PROGRAM OFFICE	33	DIRECTS INTEGRATION, ADVANCED MISSION PLANNING, AND EXPERIMENT DEVELOPMENT
ADMINISTRATIVE STAFF	33	SUPPORTS ALL ACTIVITIES OF PROGRAM OFFICE
PI/PL SPECIALIST/CREW	33	DIRECTLY CONTRIBUTES TO ADVANCED MISSIONS AND EXPERIMENT DEVELOPMENT
DISCIPLINE SPECIALISTS	50	PRIMARY LIAISON BETWEEN EXPERIMENT DEVELOPMENT AND INTEGRATION
INTEGRATION CENTER		
ALL EXCEPT PL PROJECT MANAGERS	8	ORGANIZATION SUPPORTS UP TO 24 SPACELAB FLIGHTS PER YEAR
LAUNCH SITE		
ALL EXCEPT TECHNICAL STAFF	8	ORGANIZATION SUPPORTS UP TO 24 SPACELAB FLIGHTS PER YEAR
PAYLOAD PROJECT MANAGERS	33	EACH PL/SM/EM AT LS 2 MONTHS
CARGO PROJECT MANAGERS	25	EACH SPACELAB AT LS 1.5 MONTHS

Application of the pro-rations to each of the organizations for each processing concept provides a manpower estimate that is attributable to a two-flight-per-year program such as the ATL (Table 3.2-6). Although the pro-rations were based upon a flight rate of two per year, the organizations are essentially insensitive to flight rate. Therefore, sustaining manpower requirements are on a yearly basis rather than a per-mission basis.

All previously presented data were applicable to the accomplishment of integration and checkout activities associated with an on-going program. Operational Space Shuttle and Spacelab programs were assumed. It was also assumed that the development of the operational Shuttle/Spacelab program would include general logistics plans, payload design criteria, flight hardware maintenance and refurbishment plans, interface control documentation, test and validation procedures, and other general-purpose aids to the Spacelab user. But even with this library of data, each user center will require some initial non-recurring effort to incorporate and implement the generalized operations documentation to the specific and unique applications of that user. Manpower estimates to achieve this conversion of documentation tailored to an individual user are presented in Table 3.2-7 for each of the processing concepts.

Table 3.2-6. Pro-Rated Yearly Sustaining Requirements
Two Flights Per Year
(Man-Months)

SKILL CODE	CONCEPT	I			II & VII			III & VI			IV & VIII		V	
	CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
DIRECTORS		8	1	1	8	1	1	8	1	1	8	1	8	1
MANAGERS		60	39	5	60	39	7	72	2	7	72	7	72	5
TECH SPECIALIST		104	-	-	104	-	-	104	-	-	104	-	104	-
ADMINISTRATORS		12	4	2	12	4	4	16	1	4	16	4	16	2
SECRETARIES		44	5	4	44	5	5	56	3	5	56	5	56	4
TOTALS		228	49	12	228	49	17	256	7	17	256	17	256	12
		289			294			280			273		268	

Table 3.2-7. User-Unique Non-Recurring Manpower Requirements
(Man-Months)

WBS TASK	CONCEPT	I			II & VII			III & VI			IV & VII		V	
	CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
LOGISTIC PLANS			20	3		20	3	20	6	3	20	3	20	3
EXPERIMENT DESIGN CRITERIA			50			50		50			50		50	
GSE/FACILITY REQUIREMENTS								50			50		90	
OPERATING INSTRUCTIONS			24			24		20	5		25		25	
EQUIPMENT SPECIFICATIONS			24			24		10	14		24		24	
TURNAROUND REFURBISHMENT PLAN		10	10			10	4	10	5	4	10	4	14	
ICD'S		10	10	10	10	10	10	20		10	20	10	20	10
REPAIR & REFURBISHMENT SOFTWARE			4			4		10	4		14		14	
TEST/VALIDATION SOFTWARE			8			8		8			8		8	
RELIABILITY SPECIFICATIONS		5	5		5	5		5	5		5		5	
SAFETY STANDARDS		10	10		10	10		10			10		10	
SITE ACTIVATION								40			40		100	
TOTAL (MAN-MONTHS)		35	165	13	35	165	17	253	39	17	276	17	380	13
		213			217			309			293		393	

The differences between concepts can be attributed to the delta effort associated with the derivation of GSE and facility requirements and the subsequent site activation in those concepts where tests and operations occur at the user's site. These same activities are not shown in Concepts I and II/VII because the development of the operational Shuttle and Spacelab includes these GSE/facility related activities at MSFC (integration center) and KSC (launch site).

Ground Support Equipment

The methodology used to identify the ground support equipment (GSE) requirements is depicted in Figure 3.2-12. A total of 65 different end items of GSE that may be developed by ESRO were identified. An additional 27 end items of GSE that must be supplied by the NASA were also identified.

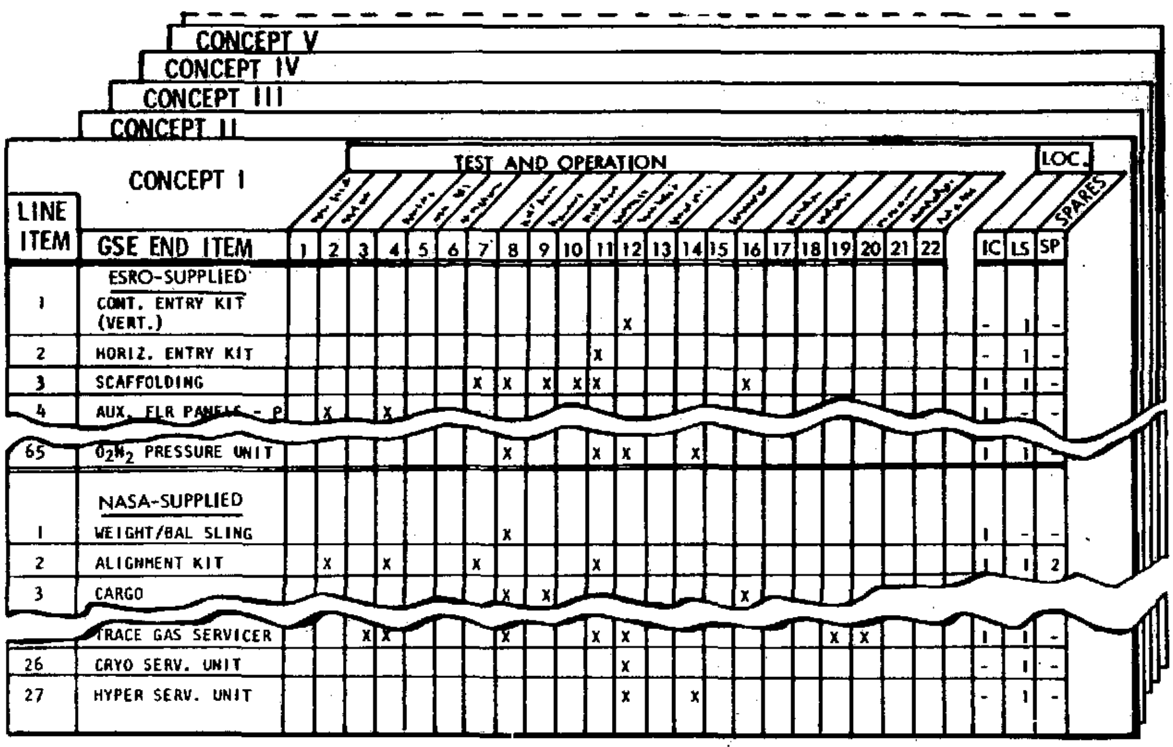


Figure 3.2-12. GSE Quantity Development

Each test and operational functional block (1 through 22) was analyzed to determine the required GSE. Caravaning of GSE between integration sites was evaluated. The complement of GSE required at each site for each processing concept was derived. The composite number of end items for each concept is presented in Table 3.2-8. As only a few items were considered reasonable candidates for caravaning between sites, the variations between concepts reflect the number of sites involved in flight hardware processing.

Table 3.2-8. ATL Program GSE Requirements Summary

GSE \ CONCEPT	COMPLETE SPACELAB			PALLET-ONLY	
	I & V	II & IV	III	VI	VII & VIII
CHECKOUT	35	42	42	44	43
HANDLING	56	55	74	56	43
AUXILIARY	46	49	60	47	37
SERVICING	20	19	24	22	17
TOTAL (END ITEMS)	157	165	200	169	140

The additional GSE required to handle and assemble the SM/EM and racks accounts for the differences between the complete Spacelab and pallet-only Spacelab processing concepts. But the complement of complete Spacelab GSE is also capable of accommodating the pallet-only Spacelab except for two items: a simulated payload specialist station at the Level III integration site, and systems igloo handling equipment at the launch site. Addition of these two items to the complete Spacelab GSE complements will permit the intermixing of the two Spacelab configurations in Concepts II, III and IV.

Facilities

A test and operations scenario was developed for each processing concept, as illustrated in Figure 3.2-13, to determine the facility requirements at each site. Time-phasing within a facility was considered in the determination. Table 3.2-9 summarizes the square-footage requirements for each site for each concept. Evaluation of the currently planned modifications of Building 4755 at MSFC indicates that all integration center requirements identified in Table 3.2-9 are more than adequately fulfilled. Similarly, the planned modifications to the MSOB (O&C) and the planned Orbiter Processing Facility at KSC will accommodate all launch site requirements identified in Table 3.2-9.

Evaluation of existing facilities at Langley Research Center indicated that Building 1293A could be modified to fulfill all user requirements identified in the table except the operations control center (OCC). In all concepts, an allowance was made for an OCC of about 2400 square feet at the user's site to provide real-time mission support capability. The OCC need not be a new building. A suitable area in an existing building could be utilized for this function. The major item associated with the OCC is the installation of a DOMSAT ground station. Trade studies indicated that the most cost-effective technique for relay of flight data to a Spacelab user during the Shuttle era was via a DOMSAT relay link from the TDRS ground terminal at White Sands, New Mexico.

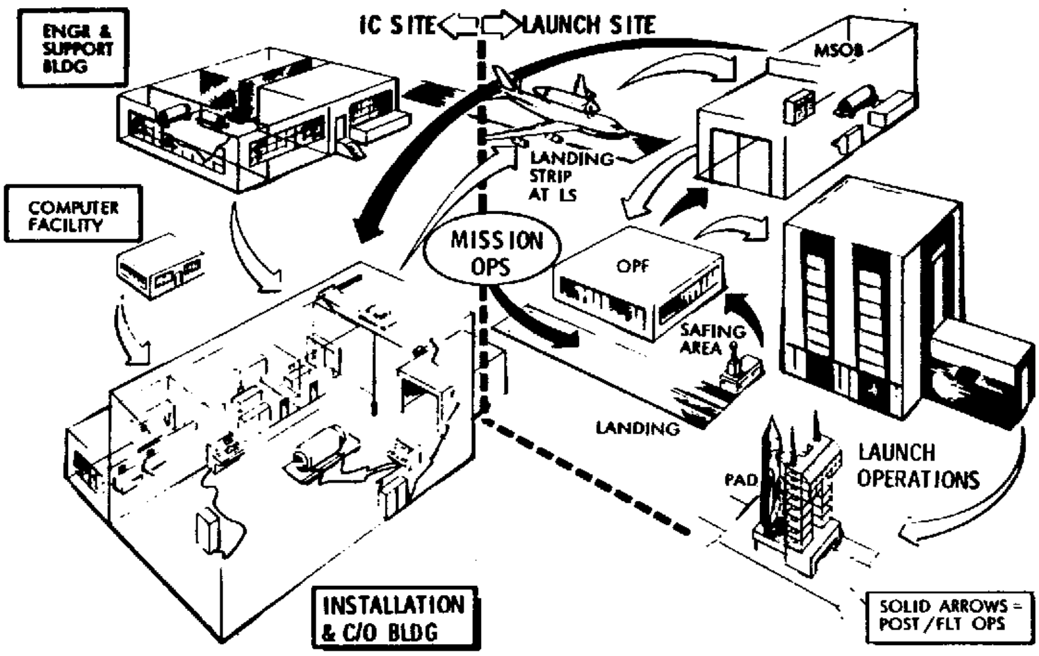


Figure 3.2-13. Typical Spacelab Processing Flow

Table 3.2-9. Summary of Facility Requirements

	SPACELAB FACILITY AREA REQUIREMENTS (FT²)												
CONCEPT	I			II/VII			III/VI			IV/VIII		V	
FACILITY / CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
WAREHOUSE & SMALL COMPONENT ASSEMBLY	5,000			5,000									
INSTALLATION AND CHECKOUT							14,000						
WAREHOUSE		6,000			6,000		6,000			6,000		6,000	
REFURBISHMENT & CHECKOUT								11,000					
INSTALLATION, CHECKOUT, AND REFURBISHMENT		18,200			18,200					18,200		18,200	
CARGO PROCESSING			7,000			15,828			15,828		15,828		7,000
ORBITER CARGO INTEGRATION			5,600			5,600			5,600		5,600		5,600
PERSONNEL OFFICE SPACE	2,600	6,000	1,000	2,700	5,500	1,600	6,500	1,800	1,600	7,800	1,600	8,300	1,000
OPERATIONS CONTROL CENTER	2,400			2,400			2,400			2,400		2,400	
SITE TOTALS	10,000	30,200	13,600	10,100	29,700	23,028	28,900	12,800	23,028	34,400	23,028	34,900	13,600
CONCEPT TOTALS	53,800			62,828			64,728			57,428		48,500	

3.3 PROGRAMMATIC COSTING

This section summarizes the programmatic costs for the eight Spacelab processing concepts. The costs are presented in three categories: mission-unique, sustaining, and non-recurring. Mission-unique costs pertain to those items that are directly attributable to the ground operations of one particular flight. Sustaining costs are primarily associated with administrative and maintenance activities. As the basic sustaining organization is relatively independent of flight rate, the pro-rations (described previously for a two-flight-per-year program) were used in determining yearly costs. Non-recurring costs include the initial effort to adapt the Spacelab documentation and procedures to a specific user and the capital investment for GSE and facilities to conduct Levels III, II, and I integration.

MISSION-UNIQUE COSTS

In addition to the development of manpower estimates for each task in the WBS, support services estimates were also developed and identified by WBS task. The derivation of the support service estimates are contained in the detailed technical report, Volume III, Resource Requirements Development. Only broad definitions and cost summaries of the support services are presented in this volume.

Table 3.3-1 summarizes the costs for the integration and checkout activities associated with and directly attributable to the ground operations of one flight. Included in the material costs are interfacing hardware such as

Table 3.3-1. Mission-Unique Costs Per Mission
(Thousands of Dollars)

COST ITEM / CONCEPT	I			II & VII			III & VI			IV & VIII		V	
CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
MATERIAL	--	69	--	--	69	--	37	32	--	69	--	69	--
TRAVEL	30	28	2	32	32	3	45	4	5	43	4	37	2
AUTO COMP	16	10	1	16	9	2	25	--	2	25	2	25	1
DOCUMENTATION	2	3	--	2	3	1.5	3	1.5	1.5	3	2	3	1
SHIPPING/TRANSPORT	16	24	--	16	24	--	44	12	--	32	--	32	--
FACILITIES	40	--	--	40	--	--	40	--	--	40	--	40	--
PERSONNEL	373	1005	148	392	916	258	1019	264	258	1230	258	1321	148
TOTALS	477	1139	151	498	1053	264.5	1213	313.5	266.5	1442	266	1527	152
	1767			1815.5			1793			1708		1679	

cables, connectors and brackets, soft mockup material and special GSE required to integrate a payload. Travel estimates include airfare and per-diem expenses. Autocomputation costs reflect the estimated run time required on a large-scale computer, such as the IBM 360, for the development of checkout and flight software and computer-aided analyses and designs. Documentation costs are solely for the publication and distribution effort. Engineering time to produce the technical contents of the documents is included in personnel estimates. Commercial air freight rates were used to estimate the shipping costs of experiment equipment between sites (Concepts I and II/VII only). As no estimates for the operation of the 747/piggyback or the C-5A are currently available, rates for use of a "Guppy" aircraft were used for the transportation of Spacelab modules. The facilities estimate reflects the projected monthly lease rate for a DOMSAT transponder channel. Both supporting function and test and operation requirements are included in the personnel estimates.

Launch site costs are essentially the same for Concepts I and V. Also, launch site costs are the same for Concepts II/VII, III/VI, and IV/VIII. Note the LS delta costs between I and V and the other concepts are almost completely assumed by the Level II integrator. In Concept I, the IC assumes the variation in LS costs; in Concept V, the user assumes these costs.

Comparison of IC and user costs in the various concepts indicates the relative or proportionate participation and cognizance of the two centers in the integration process.

The cost variations between concepts are primarily due to the differences in manpower and travel/transportation requirements. In general, the data indicate that from a composite NASA standpoint, the more services a Spacelab user sublets, the greater the total mission-unique costs will be. But the difference is only of the order of 8 percent from the high to the low estimate and, by itself, will not establish a preferred processing concept.

SUSTAINING COSTS

Table 3.3-2 summarizes the yearly sustaining costs for all eight concepts. The GSE and facility maintenance figures are based on cost estimating relationships (CER's) developed by Rockwell from previous space programs and NASA studies. The institutional base and other administrative costs are a function of the direct or mission-unique costs at each center. Personnel costs reflect average aerospace industry rates for the skill codes required by each sustaining organization and pro-rated as defined previously. Over 86 percent of the sustaining costs are attributed to personnel requirements.

The trend in the sustaining costs follows the same pattern as the mission-unique costs. The greater the direct involvement and cognizance of the user, the less the total costs. The deltas between concepts are not large ($\approx$ \$100K per year maximum). Different, but equally justifiable, pro-rations might reduce the variations to a negligible value. There is no distinct advantage to one concept over the other from the standpoint of sustaining costs.

Table 3.3-2. Yearly Sustaining Costs (Thousands of Dollars)

COST ITEM	CONCEPT	I			II/VII			III/VI			IV/VIII		V	
	CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
GSE MAINTENANCE		-	21	2	-	18	4	18	4	4	18	4	21	2
FACILITY MAINT.		-	12	1		12	2	12	3	2	12	2	12	1
INSTITUTIONAL BASE & OTHER ADMINISTRATIVE		22	38	6	23	35	10	46	10	10	54	10	57	6
PERSONNEL		494	140	26	494	140	36	550	14	36	550	36	550	26
TOTALS		516	211	35	517	205	52	626	31	52	634	52	640	35
		762			774			709			686		675	

NON-RECURRING COSTS

Other than the capital investment for the Spacelab modules, the most significant cost items to implement a processing concept are the facilities and the GSE. The costs indicated in Table 3.3-3 summarize the basic investment of the agency to process a Spacelab payload by each concept. The facility costs

Table 3.3-3. Composite Non-Recurring Costs (Millions of Dollars)

COST ITEM	CONCEPT	I			II/VII			III/VI			IV/VIII		V	
	CENTER	U	IC	LS	U	IC	LS	U	IC	LS	U	LS	U	LS
FACILITIES		0.5	3.5	0.5	0.5	3.5	0.5	2.4	3.5	0.5	2.4	0.5	2.4	0.5
GSE		--	8.9	4.9	--	6.4	8.6	6.1	2.7	8.6	6.4	8.6	8.9	4.9
SPARES		--	2.7	0.8	--	2.4	2.2	2.4	0.1	2.2	2.4	2.2	2.7	0.8
PERSONNEL		*	0.4	*	*	0.4	*	0.6	0.1	*	0.6	*	0.9	*
TOTALS		0.5	15.5	6.2	0.5	12.7	11.3	11.5	6.4	11.3	11.8	11.3	14.9	6.2
		22.2			24.5			29.2			23.1		21.1	

*LESS THAN $100K

at the user (Langley) include the operations control center (only the OCC in Concepts I and II/VII) and the modifications to Building 1293A. The facility estimate at the IC reflects a preliminary estimate for the modification of Building 4755 at MSFC (August 1974). Modifications to the MSOB at KSC are reflected in the LS facility estimate (August 1974). It should be noted that all of the proposed facilities can accommodate more than the baseline flight rate of two per year that was used in this study.

The GSE estimates reflect the basic requirement for processing either a complete Spacelab or pallet-only Spacelab configuration. The GSE in each concept can also accommodate flight rates greater than two per year. Therefore, with a given set of GSE, the support capability at any of the centers is essentially equal.

The differences between concepts in total agency costs are due primarily to duplications of GSE. For example, in Concept III/VI, three centers must be equipped with handling equipment, assembly stands, transporters, etc.

If Concept III/VI is neglected, the differences between the remaining concepts amortized over a 10-year program are not very large. The key consideration in determining the applicability or advisability of the capital investment is the utilization over the 10-year period. For example, if a user were to invest $12 million (as in Concept IV) in GSE and facilities, a relatively high utilization rate would be required. The same consideration must be given to such a capital investment at the IC or LS. Only one GSE set is indicated at the IC and LS in Table 3.3-3, but if the processing rates (payloads) saturate these singular sets, then additional sets are required. Thus, the Spacelab flight rate or processing rate is the key parameter in justifying the capital investment regardless of where the equipment is located.

3.4 CONCEPT EVALUATIONS

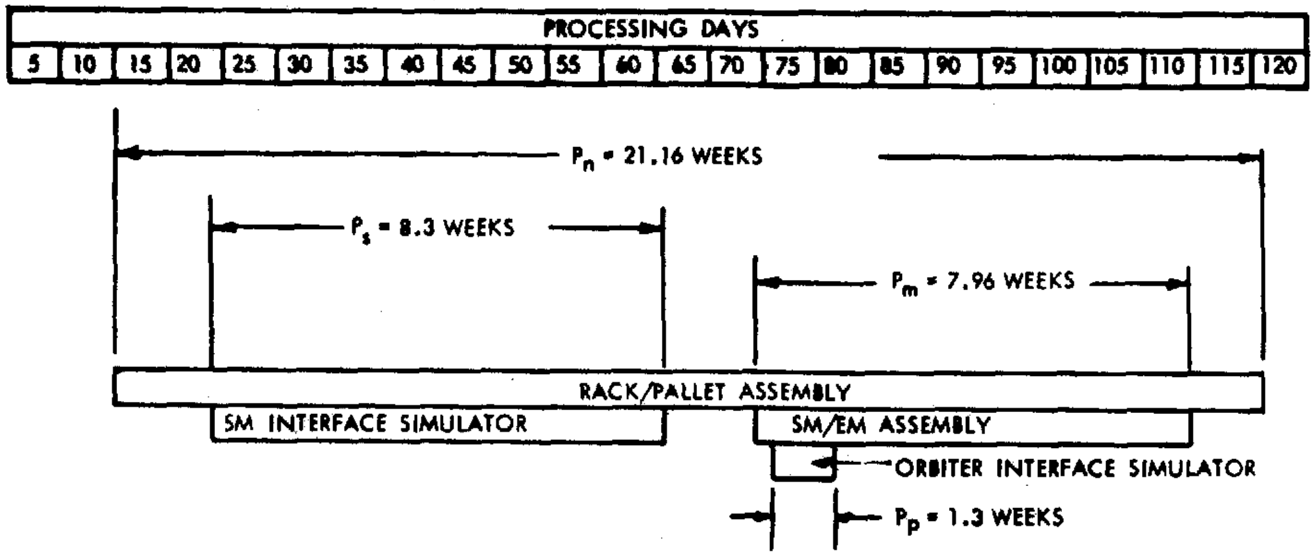
Two major concept evaluations were accomplished: flight-rate sensitivities and concept applicability. The impact on Spacelab flight hardware, GSE and facility utilization, and integration and checkout personnel requirements was parametrically evaluated for various yearly flight rates. The applicability of the alternate concepts was evaluated for geographical co-location of integration activities and launch sites, multiple ownership of Spacelab modules, and potential NASA and non-NASA Spacelab users.

FLIGHT-RATE SENSITIVITIES

The optimizations derived in this study were based upon a flight rate of two Spacelab payloads per year. But throughout this study it was recognized that for the processing concepts to be useful to the NASA agency, consideration of the entire Spacelab traffic model was required. The prime driver in the derivation of the test and operations sequences was to minimize the involvement times of Spacelab modules for each flight and, thus, maximize the number of flights per year that a Spacelab could support. Basic GSE and facility requirements for each processing concept were derived in order that an assessment of their potential utilization as a function of flight rate could be determined. Personnel and staffing requirements were established that reflected maximum utilization of all personnel involved. The staffing approach was intentionally selected to be adaptable to various flight rates. These flight-rate sensitivities are discussed in this section.

Flight Hardware Flight-Rate Sensitivity

Based upon the timed sequences of tests and operations, the per-flight involvement time of each module of the Spacelab for both configurations was determined. Figure 3.4-1 illustrates the parametric derivation of involvement times for two of the processing concepts for the complete Spacelab configuration. As the support module and Orbiter interface simulators are the single most expensive items of GSE, they are also indicated on the figure. Note that a one-week period of revalidation/maintenance was allowed for the simulators after each use. A summary of the involvement times of the Spacelab modules and simulators for the processing of two Spacelab configurations is presented in Tables 3.4-1 and 3.4-2. The Orbiter interface simulator involvement time is minimal; one unit could support the entire Spacelab traffic through one launch site. Calendar weeks are indicated based upon a single-shift/five-day work week except during Orbiter-cargo integration, which is a two-shift operation. Tables 3.4-3 and 3.4-4 present the hardware requirements as a function of flight rate. Based upon the Spacelab traffic model used in this study, a nominal of 15 complete Spacelabs and 9 pallet-only Spacelabs will be flown each year. There are only minor differences between concepts in the required hardware complement. The support module/experiment module shell (SM) and simulator utilization saturates at 5 to 6 flights per year. The support systems igloo (SI) involvement time is less than the SM because of decreased refurbishment time and thus one of the SI's will support up to eight flights per year.



ITEM NOMENCLATURE	INVOLVEMENT TIMES (CALENDAR WEEKS)	FLIGHTS/YEAR (AS FUNCTION OF E/I UNITS)
① RACK/PALLET ASSEMBLY	$P_n = 21.16$	$N_{52} = \frac{52n}{21.16} = 2.46n$
② SM/EM ASSEMBLY	$P_m = 7.96$	$N_{52} = \frac{52m}{7.96} = 6.53m$
③ SM I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_s + 1 = 8.3 + 1 = 9.3$	$N_{52} = \frac{52s}{9.3} = 5.6s$
④ ORBITER I/F SIMULATOR (ALLOW ONE WEEK FOR REVALIDATION)	$P_p + 1 = 1.3 + 1 = 2.3$	$N_{52} = \frac{52p}{2.3} = 22.6p$

Figure 3.4-1. Derivation of Hardware Involvement Times (Concepts II and IV)

Table 3.4-1. Involvement Times for Complete Spacelab Processing
(Calendar Weeks - Single-Shift Operation)

ELEMENT \ CONCEPT	I	II	III	IV	V
RACKS/PALLET ASSEMBLY	20.3	21.2	22.5	21.2	20.3
SM INTERFACE SIMULATOR	9.3	9.3	9.3	9.3	9.3
SM/EM	9.8	8.0	8.0	8.0	9.8
ORBITER INTERFACE SIMULATOR	2.3	2.3	2.3	2.3	2.3

Table 3.4-2. Involvement Times for Pallet-Only Processing
(Calendar Weeks - Single-Shift Operations)

ELEMENT \ CONCEPT	VI	VII & VIII
PALLET/EXPERIMENT IGLOOS	22.3	21.2
SUPPORT SYSTEM IGLOO SIMULATOR	9.1	9.1
SUPPORT SYSTEM IGLOO	5.8	5.8
ORBITER INTERFACE SIMULATOR (ONE UNIT SUPPORTS 20 FLIGHTS/YEAR)	2.5	2.5

Table 3.4-3. Complete Spacelab Hardware Complement
(Single-Shift Operations)

FLTS	I & V RACKS/PALLET	I & V SM	I & V SM INTER SIM	II & IV RACKS/PALLET	II & IV SM	II & IV SM INTER SIM	III RACKS/PALLET	III SM	III SM INTER SIM
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1
3	2	1	1	2	1	1	2	1	1
4	2	1	1	2	1	1	2	1	1
5	2	1	1	3	1	1	3	1	1
6	3	2	1	3	1	1	3	1	1
7	3	2	2	3	2	2	4	2	2
8	4	2	2	4	2	2	4	2	2
9	4	2	2	4	2	2	4	2	2
10	4	2	2	5	2	2	5	2	2
11	5	3	3	5	2	3	5	2	3
12	5	3	3	5	2	3	6	2	3
13	6	3	3	6	2	3	6	2	3
14	6	3	3	6	3	3	7	3	3
15	6	3	3	7	3	3	7	3	3
16	7	4	4	7	3	3	7	3	3
17	7	4	4	8	3	4	8	3	4
18	8	4	4	8	3	4	8	3	4
19	8	4	4	8	3	4	9	3	4

Table 3.4-4. Pallet-Only Hardware Complement
(Single-Shift Operations)

FLIGHTS PER YEAR	CONCEPT VI EXPMT IGLOOS	CONCEPT VI SUP SYST IGLOO	CONCEPT VI SUP SYST SIM	CONCEPTS VII AND VIII EXPMT IGLOOS	CONCEPTS VII AND VIII SUP SYST IGLOO	CONCEPTS VII AND VIII SUP SYST SIM
1	1	1	1	1	1	1
2	1	1	1	1	1	1
3	2	1	1	2	1	1
4	2	1	1	2	1	1
5	3	1	1	3	1	1
6	3	1	2	3	1	2
7	4	1	2	3	1	2
8	4	1	2	4	1	2
9	4	2	2	4	2	2
10	5	2	2	5	2	2
11	5	2	2	5	2	2
12	6	2	3	5	2	3

Because of the planned standardization of the SM and the SI, two-shift operation during the activities that involve these items was evaluated. Planning two-shift operation through Level III integration is not recommended because these activities will be mission/flight-unique. It is anticipated that most of the test and operations contingencies will occur during Level III integration. Initial scheduling of two shifts for these activities would not allow an adequate margin for contingencies.

Based upon experience from the Apollo and Saturn II programs at Rockwell, single-shift time estimates were divided by a factor of 1.8 to convert to two-shift operations schedules. Table 3.4-5 summarizes the involvement times for the SM and SI for each of the concepts for two-shift operations. Based upon these involvement times, the required complement for these items of flight hardware is presented in Table 3.4-6. The effect is significant; one less SM and one less SI is required to support the traffic model. Two-shift operations during SM and SI processing activities are recommended.

Table 3.4-5. Two-Shift Operation Involvement Times (Calendar Weeks)

CONCEPT / EQUIPMENT	I & V	II, III & IV	VI, VII & VIII
SM/EM	6.5	5.5	N/A
SUPPORT SYSTEMS IGLOO	N/A	N/A	4.25

Table 3.4-6. SM/SI Hardware Complement for Two-Shift Operations

EQUIPMENT / CONCEPTS / FLTS PER YEAR	SUPPORT MODULE		SYSTEMS IGLOO
	I & V	II, III & IV	II, VII & VIII
1	1	1	1
2	1	1	1
3	1	1	1
4	1	1	1
5	1	1	1
6	1	1	1
7	1	1	1
8	1	1	1
9	2	1	1
10	2	2	1
11	2	2	1
12	2	2	1
13	2	2	2
14	2	2	2
15	2	2	2
16	2	2	2
17	3	2	2
18	3	2	2
19	3	3	2

GSE and Facility Flight-Rate Sensitivity

The involvement times of the major items of handling, checkout, auxiliary, and servicing GSE were determined in the same manner as flight hardware involvement times (see Figure 3.4-1). In general, the GSE items associated with the installation and test station for Level III integration reach maximum utilization first. Table 3.4-7 presents the requirements for this GSE equipment as a function of flight rate for Concept IV/VIII. Although the total number of items required is dependent upon processing concept, the flight rate at which additional GSE items are required is the same for all concepts. With the recommended approach of single-shift operations during Level III integration, one test station can support four flights per year. Simulator sets and Freon/vacuum servicing units can support slightly more flights per year (six and seven, respectively) because it was assumed that interconnection of multiple test stations and these equipments could be accomplished.

Table 3.4-7. Flight-Rate Sensitivity

LINE ITEM	GSE END ITEM	GSE QUANTITY REQUIREMENTS* FLIGHTS PER YEAR 1	2	3	4	5	6	7	8
	HANDLING								
3	SCAFFOLDING } SET								
18	MAIN ASSEMBLY STAND } SET	2	2	2	2	3	3	3	4
	TOTAL	2	2	2	2	3	3	3	4
	CHECKOUT								
27	DATA PROCESSING EQUIPMENT	2	2	2	2	3	3	3	4
28	GROUND POWER SUPPLY	2	2	2	2	3	3	3	4
30	SM/IGLOO SIMULATOR SET	1	1	1	1	1	1	2	2
32	CONTROL & DATA ACQUISITION CONSOLE	2	2	2	2	3	3	3	4
33	GROUND TEST REMOTE SITE CABLE KIT	2	2	2	2	3	3	3	4
36	EXPERIMENT TEST CABLE KIT	2	2	2	2	3	3	3	4
40	GSE/FACILITY CABLE KIT	2	2	2	2	3	3	3	4
	TOTAL	13	13	13	13	19	19	20	26
	AUXILIARY								
57	INTERIOR PROTECTIVE DEVICES	1	1	1	1	1	1	2	2
58	SM/EM HATCH COVER & SEAL	1	1	1	1	2	2	2	2
24 (NASA)	GROUND AIR-CONDITIONING UNIT (PERSONNEL	2	2	2	2	3	3	3	3
	TOTAL	4	4	4	4	6	6	7	7
	SERVICING								
60	GROUND SERVICING & COOLING UNIT	2	2	2	2	3	3	3	4
63	FREON TRANSFER & SERVICING UNIT	2	2	2	2	2	2	2	3
64	VACUUM SERVICING UNIT	2	2	2	2	2	2	2	3
	TOTAL	6	6	6	6	7	7	7	10

*NOT INCLUDING SPARES

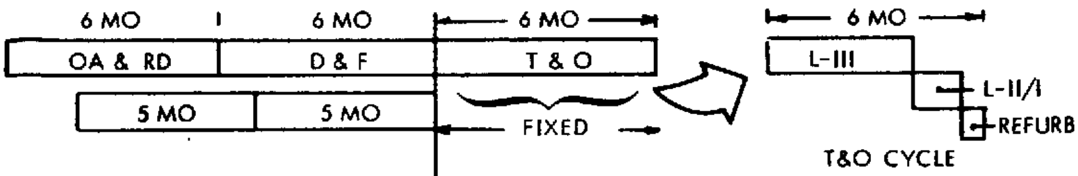
In the derivation of the facility requirements at the user center, one area in the flight hardware processing building was designated solely for disassembly and refurbishment of flight equipment. A second area was designated for equipment assembly, installation, and checkout. If each of these areas were equipped with the appropriate GSE, the facility could accommodate the yearly processing of eight Spacelab payloads in Concept III/VI, seven in Concept IV/VIII, and six in Concept V with single-shift operations. The variation in capabilities reflects the disassembly/refurbishment of flight hardware off-site in Concept III/VI and the additional task of Level II integration in Concept V. The facilities at the IC (MSFC Building 4755) and LS (KSC MSOB) can accommodate the anticipated Spacelab traffic model if two-shift operations are used.

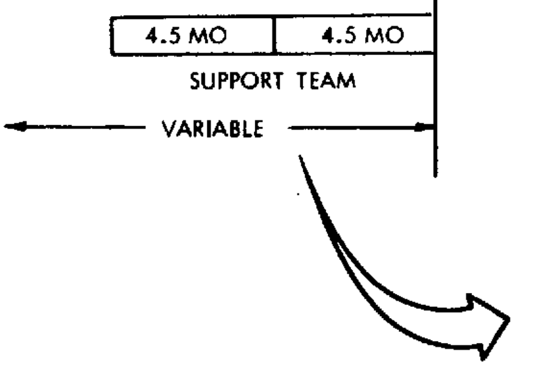
Personnel/Staffing Flight-Rate Sensitivity

The primary criterion in the development of personnel/staffing requirements was maximum utilization of the personnel involved. It was previously shown (see Figures 3.2-7 and 3.2-8) that for a two-flight-per-year rate, each phase of the support function activities (operations analysis/requirements definition and design/fabrication of interface hardware) should be scheduled to correspond to the time duration of the test and operations activities. Scheduling, phasing and staffing of each support function task was tailored to achieve this relationship between the three phases of integration and checkout activities. In determining the potential impact of flight rate on the staffing requirements, variations in the schedule of support function activities were considered. Durations of 4.5, 5.0 and 6.0 months for each phase of support function activities were evaluated. In all cases the duration of the test and operations activities was held constant at 6 months, which was the nominal time required by all processing concepts. Figure 3.4-2 illustrates the interrelationship of integration and checkout phases.

The "support team" section of the table in Figure 3.4-2 indicates the number of each type of team that would be required to support each support function phase for flight rates of 1 to 16 per year. The decimal entries in the table indicate that portion of the team(s) capacity/capability that would be utilized to support a given flight rate. As partial teams are impractical the next integer is the required number of teams. For example, at three flights per year, two 4.5-month teams are required. But only 56 percent of each team's capability would be utilized; the remainder is idle time. Therefore, the team approach with the least amount of idle time is preferred.

The key factor is the utilization of the teams; it is not the number of teams. The composite number of man-months required to accomplish the task is the same regardless of the time duration. Therefore, a team that accomplishes the support function phase in 4.5-month increments is 33-percent larger than a team that accomplishes the same tasks in 6-month increments. For example, at a flight rate of 10 per year, only four 4.5-month teams are required whereas five 6-month teams are required. But the 6-month teams are fully utilized. A 25-percent inefficiency (each 4.5-month team is idle 6.25 percent of the time) results with the 4.5-month teams that are significantly larger than the 6-month teams (e.g., 6-month team = 100, total 500; 4.5-month team = 133, total 533). The preferred approach is the 6-month scheduling of support function phases at 10 flights per year and at most of the other flight rates also.





FLIGHT RATE	SUPPORT TEAM ACTIVITY DURATION 4.5 MO		5.0 MO		6.0 MO		T&O TEAM * L-III (3/YR)	L-II/I (8/YR)	REFURB (24/YR)
1	0.37	1	0.42	1	0.5	1	1	1	1
2	0.75	1	0.83	1	1.0	1	1	1	1
3	1.12	2	1.25	2	1.5	2	1	1	1
4	1.50	2	1.67	2	2.0	2	2	1	1
5	1.87	2	2.08	3	2.5	3	2	1	1
6	2.25	3	2.50	3	3.0	3	2	1	1
7	2.62	3	2.92	3	3.5	4	3	1	1
8	2.99	3	3.33	4	4.0	4	3	1	1
9	3.37	4	3.75	4	4.5	5	3	2	1
10	3.75	4	4.17	5	5.0	5	4	2	1
11	4.12	5	4.58	5	5.5	6	4	2	1
12	4.50	5	5.00	5	6.0	6	4	2	1
13	4.87	5	5.42	6	6.5	7	5	2	1
14	5.25	6	5.83	6	7.0	7	5	2	1
15	5.62	6	6.25	7	7.5	8	5	2	1
16	5.99	6	6.67	7	8.0	8	6	2	1

*DURATION FIXED AT 6 MONTHS

LEGEND
(X) PREFERRED STAFFING APPROACH
L-III LEVEL III INTEGRATION
L-II/I LEVELS II AND I INTEGRATION

Figure 3.4-2. Personnel Flight-Rate Sensitivity

There also is staffing flexibility in the performance of test and operations tasks. The use of part-time help in the performance of T&O tasks was indicated previously. But the sequential and discrete activities associated with Levels III, II/I and refurbishment operations would permit the dedicated assignment of personnel to each of these three phases of flight hardware processing. For example, at a flight rate of 8 per year, 3 T&O teams dedicated to just Level III integration would be required; one team dedicated to Level II/I integration would be required; and one team could be used on a part-time basis for refurbishment activities.

CONCEPT APPLICABILITY

The prime factors in determining concept applicability was the planned flight rates of the user and the availability/utilization of GSE and facilities at alternate integration sites.

Co-Location of Integration Center and Launch Site

Complete Spacelab Processing Concept I was defined as Levels III and II integration, and Spacelab hardware ownership being the responsibility of a centralized Spacelab integration center that was geographically separated from the Shuttle launch site. An evaluation was conducted to determine if geographical co-location of the IC/LS would be advantageous. This evaluation is summarized in Table 3.4-8.

Table 3.4-8. Evaluation of Integration Center/Launch Site Co-Location

CONSIDERATION	IMPACT	RATIONALE
PERSONNEL	NONE	COMPLEXITY/MAGNITUDE OF SPACELAB & SHUTTLE INTEGRATION REQUIRES 2 DEDICATED ORGANIZATIONS
PERSONNEL TRAVEL	MINOR COST DECREASE; IMPROVED EFFICIENCY	ELIMINATES LS-IC COORDINATION TRIPS ~\$6000/FLIGHT FOSTERS MORE FREQUENT/INFORMAL COORDINATION
TRANSPORTATION	DECREASES SHIPPING COSTS	COMPLETE SPACELAB OR RACKS/PALLETS NEVER LEAVE THE IC/LS; PER-MISSION SAVINGS ≈ \$20,000
USER INTERFACE	MINOR TRAVEL REVISION	TWO ORGANIZATIONS AT IC/LS; SAME TASKS--SAME PERSONNEL/SHIPPING ESTIMATES
GSE	NONE	LEVEL III INTEGRATION, INSTALLATION & CHECKOUT STAND REQUIRED IN EITHER CASE
FACILITIES	MAJOR CAPITAL INVESTMENT	MODIFIED O&C AT KSC CAN ACCOMMODATE 20 TO 25 LEVEL II INTEGRATIONS PER YEAR + CONTINGENCY LEVEL III'S; DELTA FACILITY REQUIRED AT KSC

CONCLUSION ⇨ FACSIMILE DUPLICATION OF EXISTING/AVAILABLE BLDG 4755 AT MSFC NOT WARRANTED; CO-LOCATION NOT RECOMMENDED

The magnitudes of the Spacelab integration task and the Shuttle integration task preclude the combining of them into one task set. It would be the equivalent of combining the individual CSM and LM integration of the Apollo program into one task with the integration of the Saturn V launch vehicle. Separate, independent organizations are required up to the point of integration <u>between</u> program elements.

Estimates of trips for coordination between integration center personnel and launch site personnel were on a man-day, per-diem basis. With co-location this line item would disappear. Although the cost savings is only of the order of \$6000, the actual benefits of co-location are probably greater. Co-location would foster more frequent and informal coordination.

Co-location of the two activities would negate the preflight and post-flight shipment of the Spacelab which requires the use of the 747/piggyback configuration. Intra-site moves would be required but would cost significantly less than an air ferry operation. Net savings would be of the order of \$20,000 per mission.

Only minor revisions in the user interface would result. Coordination with two organizations would still be required, but coordination meetings could be scheduled to be accomplished with the co-located organizations on a single trip.

The most significant consideration is the availability of the required facilities. If only a single Spacelab program such as the ATL, or a periodic Spacelab user is considered, then current plans for modification of the MSOB at KSC would support both Levels III and II integration at the launch site. But the Level III integration capability planned for the MSOB will not accommodate the anticipated Spacelab traffic model. Therefore, an additional capability/facility would be required. With the availability and applicability of Building 4755 at MSFC, it does not appear to be cost efficient to duplicate this facility at the LS for the minor preflight savings that could be achieved. Also, a more reasonable use of the Level III integration capability at KSC would be for contingencies and periodic users such as foreign countries, rather than a continuing program such as the ATL.

Western Test Range Implications

The impact on the processing concepts that would result from the activation of the Western Test Range (WTR) as a second Shuttle launch site was assessed. Three of the major options for processing Spacelabs through WTR are indicated on Table 3.4-9. Actually, these "options" are more characteristic of a site activation plan. Initial Spacelab flight rates from WTR do not warrant the capital investment for dedicated GSE and facilities. A "ship and shoot" approach would be the most cost-effective method for low flight rates. That is, Level II integration would be accomplished off site from WTR and the integrated Spacelab (either configuration) would be shipped to WTR for Level I integration with the Orbiter.

Table 3.4-9. Western Test Range Implications

APPROACH	CONCEPT		
"SHIP & SHOOT"	COMPLETE LEVEL II INTEGRATION AT KSC; DELIVER SPACELAB TO WTR FOR DIRECT INSTALLATION/ INTEGRATION INTO ORBITER	1	LOGICAL WTR SITE ACTIVATION PLAN
TRANSIENT CREW	PROVIDE KSC CREW TO WTR FOR LEVEL II INTEGRATION AT WTR WITH GSE/FACILITIES	2	
INDEPENDENT OPERATIONS	PERFORM LEVEL II INTEGRATION WITH RESIDENT CREW AT WTR	3	

As the Spacelab flight rate from WTR reaches about 5 or 6 per year, dedicated GSE and facilities become practical. The flight-rate sensitivity data, presented previously, indicated that at these flight rates (with single-shift operation) full-time utilization of major equipments and resident personnel was achieved. During the transition phase from low flight rate to rates of 5 to 6 per year at WTR, utilization of a transient crew from the Level II integration site could be advantageous and expedite the activation/ certification of autonomous operations at WTR.

The operation of a second Shuttle launch site would have no significant effect on a Spacelab user. Previously defined coordination/interfaces would be applicable to either KSC or WTR. During the WTR activation period, scheduling of a transient crew from the Level II integration site would be a significant problem. The transition from dependent to independent WTR operations should be accomplished as quickly as possible.

Support Module/Systems Igloo Ownership

A summary of the considerations in defining the preferred support module and/or systems igloo (SM/SI) ownership is presented in Table 3.4-10. Ownership of the SM/SI by the common user is not recommended. These two items are the largest single capital investment of the Spacelab program. As almost continuous utilization of the SM/SI can be achieved if ownership is by either the LS or IC, it would be difficult to justify such a large user capital investment with only partial utilization. It is recognized that security constraints may require some users (e.g., DOD) to own the SM/SI regardless of utilization rates.

Table 3.4-10. Support Module/Systems Igloo Ownership Evaluation

OWNERSHIP	CONSIDERATIONS
• USER	• SM/SI LARGEST CAPITAL INVESTMENT • 100% UTILIZATION REQUIRED, ~5 FLTS/YR/ELEMENT • DELTA GSE REQUIREMENTS, ≈$2.9M • SECURITY CONSTRAINTS MAY REQUIRE OWNERSHIP
• INTEGRATION CENTER • LAUNCH SITE	• EITHER SITE CAN ACHIEVE HIGH UTILIZATION • TRAFFIC MODEL SUGGESTS ORBITER ASSIGNMENT TO SPACELAB PROGRAM • EVOLVING SL DESIGN INDICATES HIGHLY STANDARDIZED SM/SI-ORBITER INTERFACE • SM/SI COULD EVOLVE TO ORBITER KIT STATUS • IF IC-OWNED, 747/PIGGYBACK TRANSPORT REQUIRED • IF LS-OWNED, DELTA GSE ≈$700K
CONCLUSION ⇨	• USER-OWNED ONLY FOR SECURITY REASONS OTHERWISE • LAUNCH SITE-OWNED TO MAINTAIN COGNIZANCE OF STANDARDIZED INTERFACE CENTRALIZED

Evaluation of ownership of the SM/SI by either the IC or LS is dependent upon the Spacelab flight rate and the standardization of the SM/SI-Orbiter interface. The traffic model used in this study indicates a nominal flight rate of 24 Spacelabs per year. This flight rate suggests the assignment of at least one Orbiter to Spacelab flights only. The evolution of the SM/SI configuration indicates a highly standardized interface with the Orbiter. The SM/SI could evolve to the status of an Orbiter kit.

If the SM/SI were maintained at the launch site, the 747/piggyback transport mode would not be required. In most cases, racks and pallets can be shipped by the C-5A. However, separation of the Level II and Level III integration activities does result in the duplication of certain items of GSE for the handling of racks and pallets at two sites that total about $700 thousand.

Amortized over a 10-year program, the delta GSE required at the LS for handling of racks and pallets at a second site does not appear to be a discriminator. It would appear to be more advantageous to retain the cognizance of a standard flight item and a standard interface within one NASA center. Maintenance of the SM/SI at the LS and performance of Level II integration at the LS is the preferred approach.

General Concept Applicability

A summary of the evaluations of each of the candidate processing concepts is presented in Table 3.4-11. Concept I is not recommended for the reasons and rationale presented above. Concept II/VII is the preferred Spacelab processing concept for the majority of users. Flight rates, payload complement, and program duration for most Spacelab users would not warrant the large capital investments required for user ownership and/or integration. Concept III/VI would be applicable only in the unique situation where a user could justify the capital investment but required outside support in design and fabrication activities. Such a situation would be unlikely for a multi-flight, multi-year program. Concept IV/VII is applicable to Spacelab users that plan multi-flight, multi-year programs. Amortization of capital investments with relatively high utilization rates is practical. As this class of user will usually require an SM and an SI (both Spacelab configurations) the utilization of the facilities and GSE can be quite high but the utilization of each of the units of the Spacelab could be low. Thus, user ownership of the SM/SI even in a multi-flight, multi-year program is not recommended. Only security constraints would justify the adoption of Concept V.

Table 3.4-11. Concept Evaluations

CONCEPT	APPLICATION	RATIONALE
I	NONE	• OWNERSHIP OF SM/SI BY LAUNCH SITE PREFERRED • COGNIZANCE OF STANDARD INTERFACE MAINTAINED BY ONE CENTER
II/VII	MULTI-SPONSOR PAYLOADS AND PERIODIC USERS	• MINIMIZES USER CAPITAL INVESTMENT, PROVIDES CENTRALIZED CAPABILITY FOR COORDINATION/INTEGRATION OF MULTI-SPONSORED PAYLOAD; MINIMIZES DUPLICATIONS AT MULTI-SPONSORS
III/VI	EXTREMELY LIMITED	• APPLICABLE ONLY TO HIGH-RATE/LONG-DURATION USERS THAT DO NOT HAVE DESIGN/FABRICATION CAPABILITY
IV/VIII	LONG-TERM MULTI-MISSION DEDICATED USER	• HIGH-RATE/LONG-DURATION PROGRAM JUSTIFIES CAPITAL INVESTMENT, PROVIDES DIRECT CONTROL OF LEVEL III INTEGRATION ACTIVITIES INCLUDING DESIGN/FAB, MAXIMUM FLEXIBILITY FOR CONTINGENCIES & FEEDBACK FROM PREVIOUS MISSION
V	SECURED PAYLOADS	• CAPITAL INVESTMENT FOR SM/SI PRECLUDES COMMON USER • APPLICABLE FOR DOD CLASSIFIED "SHIP-AND-SHOOT" PAYLOADS

Recommended ATL Program Concept

The current planning of the ATL Spacelab program indicates that Concept IV/VIII would be applicable. The flight rate and program duration warrant the required capital investment for GSE and facilities. An existing facility at Langley (Building 1293A) can be modified to accommodate the installation, checkout, and refurbishment activities. The 2 to 4 flights per year will result in a relatively high utilization (40 to 80 percent) of both the GSE and facilities. These flight rates would not warrant ownership of the SM/SI by Langley.

The diversified technology and multiple experiments in each ATL payload can be more readily integrated, especially in contingency situations, if direct and local control of the activities is maintained by Langley. Reflight of experiments is planned. Some equipment could be maintained by Langley in the flight configuration until the next applicable mission. Also, incorporation of mission results into payloads in process can be more readily achieved if ownership, design, fabrication, and Level III integration responsibilities are maintained by Langley.

3.5 SUMMARY

A succinct summary of the significant results and conclusions of the analyses of the study are presented below.

- Combined software and hardware verification is feasible and practical.
- Use of interface simulators is recommended to decrease the required complement of SM/SI's to support the Spacelab traffic model.
- The required preflight and postflight processing time for the receipt of flight-rated experiment equipment through postflight refurbishment of Spacelab modules is approximately six calendar months for all concepts.
- The preferred scheduling of supporting function tasks is for each phase (analysis and design/fabrication) to match the duration of the tests and operations phase (six months each, 18-month cycle per flight).
- The per-flight tasks will require approximately 105 equivalent man-years of effort.
- The pro-rated yearly sustaining/administrative support for a two-flight-per-year program will require approximately 23 man-years of effort.
- The requirements to integrate and check out the pallet-only configuration are essentially the same as for the complete Spacelab configuration.
- Composite per-mission/flight costs range from \$1.7 million to \$1.8 million across the concepts.
- Composite yearly sustaining costs range from \$0.67 million to \$0.79 million across the concepts.
- Non-recurring costs and specifically utilization of the capital investments for GSE and facilities is the primary discriminator in concept applicability.
- Scheduling of single-shift operations is recommended for Level III integration; two-shift operations are recommended for Level II/I integration.

- Two support modules and one systems igloo will support the projected Spacelab traffic model.
- Saturation of Level III GSE occurs at 4 to 5 flights per year.
- Based upon the availability and applicability of existing facilities, co-location of the integration center and the launch site is not recommended.
- Ownership of the SM/SI by the launch site is preferred.
- The activation of a second Shuttle launch site at WTR does not perturb the processing concepts developed in this study if steady-state operations are assumed.
- Performance of supporting functions and Level III integration at a centralized integration site (Concept II/VII) such as MSFC is the recommended processing concept for periodic Spacelab users.
- Performance of supporting functions and Level III integration at the user's site (Concept IV/VIII) is recommended only if a long-duration/2-to-4 yearly flight rate program such as the Langley ATL is planned.

4.0 PROPOSED ADDITIONAL EFFORT

The various facets of the integration and checkout activities for the processing concepts derived in the study were essentially developed to a uniform depth. However, as the study progressed it was apparent that certain items/topics could have a more significant impact on the optimization and definitization of the concepts. A more detailed analysis of these topics could enhance the understanding and implementation of Spacelab-payload integration and checkout. A synopsis of topics that warrant additional analysis effort is presented below.

ATL SOFTWARE REQUIREMENTS

In SUIAS it was assumed that a mixture of manual, remote control, and automated operations would be used. The adopted checkout approach included simultaneous software-hardware verification. However, the advisability of automation of experiments (and the resultant software) was not evaluated. It is suggested that alternate mechanization approaches be evaluated to determine the least costly approach for operation of Spacelab payloads. The baseline ATL payloads used in SUIAS will provide a broad spectrum of experiments to be considered. The primary objective of the proposed mechanization study would be to establish criteria for the selection of the preferred experiment mechanization and definitize software requirements where applicable.

INTERFACE VERIFICATION

At the time estimates for interface verification activities were made in the SUIAS study, only broad definitions of Shuttle and Spacelab SM/SI interfaces were available. With the evolving design of these two Space Transportation System elements and the definitization of the ATL experiments, it is now feasible to detail the specific tasks required to accomplish the various levels of interface verification. SUIAS results indicated the criticality of SM/SI involvement times. Shuttle turnaround times are even more critical. Instead of relying upon allocation times for programmatic planning, the current design definition of the Orbiter, Spacelab, and ATL equipment can provide detailed-quantified assessment data, and thus, programmatic planning with a high degree of fidelity could be accomplished.

STANDARDIZED MISSION PLANNING

The manpower required to accomplish the support functions was approximately eight times greater than the manpower required to accomplish the test and operation activities. The primary contributor to this disparity was those tasks associated with mission planning. Although a limited amount of standardization was assumed in the development of the mission/flight plan, it is believed that significant reductions in the per-mission tasks could be realized if appropriate planning and design computer programs were developed. Langley's Manned

Activity Scheduling System (MASS) is a first-step in the automation of mission planning activities. It is proposed that a study be conducted to define and develop "tools" similar to MASS for trajectories, truth sites, attitude profiles, consumables scheduling, flight timelines, and other related mission planning activities that are readily accessible to and usable by Spacelab users. Similar tools could also be developed to assist/expedite the design activities. Panel layouts, automated wire routing, and center-of-gravity control programs are candidates for automation/computer-aided design. Although the initial costs of developing these computer programs may be appreciable, it is believed that the reduction in per-mission costs would more than offset the initial investment.

REAL-TIME MISSION SUPPORT

During previous manned space programs, real-time mission support was accomplished by means of the Mission Control Center (MCC) at JSC. This facility probably will be the control point for Shuttle/Orbiter operations. It is unrealistic to assume that the MCC will also accommodate all the Spacelab users. The frequency of Spacelab flights would preclude the modification/reformatting of control and display consoles that would be required by the broad spectrum of users. Also, the ground support personnel for the payloads would have to be temporarily relocated at JSC for almost every mission.

The alternative to centralized MCC mission support is to provide real-time data to the user at the user's site. A preliminary evaluation of alternate flight data dissemination options that was conducted in SUIAS indicated a preference for relaying of real-time mission data from the TDRS ground terminal to various sites via a DOMSAT relay link. Use of leased ground lines for wide-band data resulted in excessive recurring costs. Because of the long lead time involved in establishing and activating a data dissemination system that includes geosynchronous satellites and ground terminals it is imperative that a detailed analysis of this facet of flight operations be conducted in the near future.

It is recognized that GSFC is and has been analyzing this problem. The additional effort that is proposed here is user-oriented. An evaluation of the required data transfer and real-time mission support of the currently identified Spacelab users, domestic and foreign, is required to ensure that the evolving technique will provide the necessary capability/access/control to a broad spectrum of Spacelab users.

ADVANCED TECHNOLOGY LABORATORY DEFINITIZATION

The design and development status of the Shuttle and the Spacelab, coupled with the baseline ATL experiments and payloads, will permit an in-depth definitization of the first set of ATL Spacelab flights. In general, all analyses conducted thus far on the ATL have been at a Phase A level of detail. By conducting analyses at a Phase B level of detail at this time the ATL program could be at an operational status concurrent with achieving operational status on the Shuttle and Spacelab. The SUIAS study synthesized an approach to accomplish all of the integration and checkout tasks for a

Spacelab payload. The intent of the proposed additional effort is to apply/improve/modify/verify the SUIAS techniques with detailed analyses of the candidate ATL payloads for each task except fabrication of interface hardware and flight hardware checkout. The design of equipment layouts and interface hardware should be included. Also, detailed logistics plans and flight operations should be generated. The proposed Phase B effort would uncover and resolve integration problem areas, identify alternate/more cost-effective techniques, and demonstrate a realistic, workable sequence of activities that would support a multi-flight per year, multi-year program in an efficient, cost-effective manner.